Volume XVIII. *May, 1904.* *Number 5.*

THE

PHYSICAL REVIEW.

POTENTIAL PHENOMENA IN VACUUM TUBES DURING THE PRODUCTION AND INTERRUPTION OF ELECTRICAL DISCHARGE.

By S. N. Taylor.

WHEN electrical energy is passing between the electrodes of a vacuum tube we know that the discharge may be either direct or alternating, continuous or disruptive; but not very much seems to be known, except in the case of the continuous discharge, concerning the variations in potential which occur in any of these cases. It was with the hope that something more might be learned regarding this question that, at the suggestion of Professor E. Wiedemann, I began the investigations described in this paper. The work was done in the Physical Laboratory of Erlangen University and I have to thank Professor Wiedemann for many valuable suggestions made during the continued progress of the work. Professor Schmidt and Dr. Wehnelt also have given valuable assistance.

Numerous experiments have been made in connection with the work, but this paper attempts to give only some of the preliminary results obtained. More complete results will be given later when other tests have been completed.

General Outline of the Work.

The first series of tests were made by calorimetric methods. Judging from previous results obtained by other investigators, it was thought that, if the anode were connected to earth, the average fall of potential at the cathode for either continuous or dis-

ruptive discharge could be determined from the total heating effect, using the well-known equation $H = 0.24\ EI$. In the course of the experiments, however, it appeared that better results could be obtained by means of the Braun tube, and after making simultaneous determinations by the two mothods the heat measurements were for the time being discontinued.

By means of the Braun tube we were not only able to determine the potential difference with considerable accuracy, but also to observe the variations of potential and the frequency of discharge. By means of it new and interesting facts were found out regarding the maximum and mininum potential of disruptive discharge; namely, that the potential rises to a certain maximum height and then suddenly falls off to a minimum value, but never to zero. Both the maximum and minimum values for any tube depend upon the particular conditions under which the tube is tested.

In connection with the work, a method was found by which the Braun tube can be conveniently used to measure high potentials, say of 1,000 or 1,200 volts, where the fluctuations are not too great. When the limits of variation are great, however, say 500 volts or more, the problem becomes more difficult; but a new method is given below which overcomes those difficulties quite satisfactorily.

The measurements show that the manner in which the potential develops and falls off is very largely affected by the capacity of the circuit.

Tests were also made to ascertain the effect upon the potential produced by reversing the direction of the current or by interchanging the electrodes, which show why certain results obtained by other investigators are in disagreement with one another.

I. APPARATUS.

The apparatus used in these tests included a storage battery of 1,120 cells, a twenty plate influence machine driven by a Schmidt water motor, a single plate influence machine driven by an electric motor, two Sprengle pumps, McLeod pressure gauge, a Wiedemann galvanometer, with rubber insulated coils, having a constant of 38×10^{-6} amperes per centimeter, two telescopes, a rotating mirror,

sensitive thermometers, two Kohlrausch condensers, an electric tuning fork, two static voltmeters reading to 10,000 volts, a Kelvin multicellular voltmeter, a telephone receiver, and vacuum tubes of various forms. In addition to these the parts which call for special description are as follows:

(*a*) *Cup Calorimeter.* — Fig. 1 shows a simple form of calorimeter discharge tube. *A* denotes a vacuum tube about 22 mm. long and about 13 mm. in diameter, surrounded by a glass calorimeter vessel *B* into which a liquid is placed. Both parts are made as small and light as possible so that the changes in temperature produced by the passage of the electrical discharge through *A* will be as great as possible. The water equivalent of the whole apparatus including the thermometer and 6 cubic cm. of terpentine, was found to be 8.03 by careful measurement.

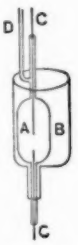


Fig. 1.

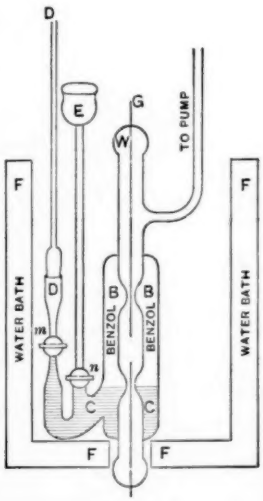


Fig. 2.

(*b*) *Apparatus D* as shown in Fig. 2 is a form of the Bunsen calorimeter as modified to meet the requirements of these investigations. It is all made of glass and all the joints are fused, except *WW* where the aluminium electrodes *GG* are sealed in with wax. The vacuum tube *A* is enclosed by an outer vessel *BC* of which the upper part *BB* is filled with benzol and the lower part *CC* is filled with mercury all air being carefully removed. *M* and *N* are ground glass stopcocks and *E* is a tube which is convenient for introducing the liquids into the outer vessel. When *BC* has been filled with benzol and mercury, *N* is closed and *M* is opened. Then when the electric discharges are developed in *A*, the benzol becoming warmed expands and causes the mercury to rise in the capillary tube *DD*. The bore of *DD* being less than a millimeter in diameter, a very slight change in the temperature of the benzol produces a large variation in the length of the mercury column. A millimeter scale being placed directly behind the mercury column, the length of the col-

umn can be read to a tenth of a millimeter by means of a telescope placed some distance away.

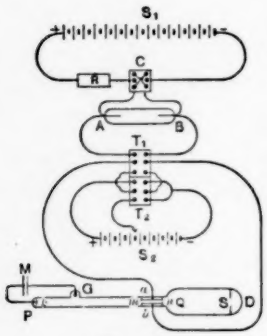


Fig. 3.

(*c*) The Braun tube as used in these measurements is the form adopted by Dr. A. Wehnelt (Verhandlungen der Deutschen Physikalischen Gesellschaft, January, 1903) for potential comparisons, the potential plates being inside the glass tube. The form is represented in Fig. 3 where *PQ* is a glass tube 53 cm. long and 3 cm. in diameter fused to a larger cylinder *QD* 22 cm. and 8 cm. in diameter. *S* is a fluorescent screen fastened to the walls of the large tube by means of glass plugs. The cathode *k* consists of an aluminium disc 1.5 cm. in diameter located at the extreme end of the small tube as far from *S* as possible. The anode *G* is situated in a short side tube which projects perpendicularly from *PQ* about 15 cm. from the end *P*.

The potential terminals *a* and *b* are flat plates of aluminium 8 cm. long and about 2 cm. wide. To the center of each of these is riveted a thick aluminium wire which, passing through the walls of the tube, is firmly attached to the glass. The plates are thus held rigidly in position 2 cm. apart and parallel to the axis of the tube. Electrical contact is made with them by means of platinum wires sealed in the glass. At each end of these plates is a mica diaphragm *m* and *n* fitted closely to the inner wall of the cylinder. The diaphragm *m* has an opening at its center only 1 mm. in diameter but the opening in the diaphragm *n* is some twenty millimeters in diameter. The purpose of these diaphragms is to intercept all unnecessary cathode rays. The bundle of rays which enters between the plates is only one millimeter in diameter, and that will be the size of the bright spot produced by it upon the fluorescent screen. Thus when a sufficiently high vacuum has been produced within the tube, and some 8,000 or 10,000 volts have been developed between the electrodes, a small greenish bright spot will be seen upon the screen *S* and its position thereon can be accurately read by a suitable scale. If, however, there is a difference of potential between

the plates *a* and *b* the cathode ray will be deflected; the displacement of the spot upon the screen will be proportional to the potential difference, and affords a method of potential measurement.

(*d*) For measuring the displacement of the fluorescent spot upon the screen the method used was as follows: A telescope was placed in convenient position some 2 meters away from the Braun tube and focused upon the screen *S*. At the left of the telescope and at a distance from it equal to that between the telescope and the screen, was placed a millimeter scale made of thick plate glass upon which the divisions and numbers had been cut by means of a diamond. One end of the scale was fitted tightly into an opening made into an opaque box. Inside of the box was placed a lighted glow lamp, and the only light transmitted from the box was made to pass through the opening into which the scale was fitted. The light which was thus emitted passed through the entire length of the glass plate and being totally reflected internally by the polished walls of the glass, nothing of the scale could be seen in a dark room,

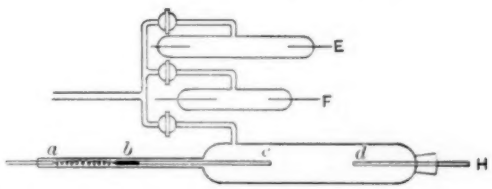


Fig. 4.

except the division marks and numbers which stood out as so many bright lines. With proper adjustment this scale could be read very distinctly several meters away. By means of a mirror obliquely placed the image of this illuminated scale was reflected into the telescope in such a way that the spot on the screen *S* which could be seen at the same time through the telescope appeared to be located upon the illuminated scale. Thus the position of the fluorescent spot could be read at any time, and any change in its position or displacement of the spot could be thus read in millimeters.

(*e*) *Discharge Tubes.* — To test the effect produced by having the discharge take place under different conditions various discharge tubes were used, some of which are represented in Fig. 4. The tubes *E*, *F* and *H* were connected to the vacuum pump at the same

time so that the vacuum condition would be the same in all of them and the difference in the discharge phenomena obtained from them, if any, would be due simply to the different forms or dimensions of the tubes. The dimensions of these tubes are as follows:

Tube.	*E*	*F*	*H*
Diameter,	3 cm.	4 cm.	4.5 cm.
Length,	32	21	65
Distance between Electrodes,	1.5	14	Variable.

In tube *H* the electrodes are aluminium with the exception of the portion which connects *a* to *b* which is a fine copper wire wound in a spiral, while the portion *b* is iron and attached rigidly to *c*. If a strong electromagnet is applied to the outside of the tube the position of *bc* can be changed at pleasure and the distance between *c* and *d* can be made any desired magnitude.

II. Method of Determining the Mean Potential Difference by Calorimetric Methods.

If the total heat developed in the discharge tube can be measured then $H = 0.24EI$ and knowing the current I we can calculate the mean potential E. All heat measurements were made with the apparatus surrounded by a water jacket kept at constant temperature. In addition to this precaution, corrections were always made for radiation by observing the rate of gain or loss in temperature for the five minutes immediately before the current was turned on, and for the five minutes immediately after it was turned off. The current was always passed through the tube for ten minutes and a mean correction for the radiation was thus calculated.

The first heat measurements were made by the simple cup calorimeter of Fig. 1. In these the changes in temperature were measured directly by sensitive thermometers which were read accurately to tenths of a degree and estimated to hundredths of a degree by means of a telescope. The current which, passing through the tube, cause the rise in temperature, was measured by the Wiedemann galvanometer with rubber insulated coils, the constant of the instrument being 38×10^{-6} per centimeter deflection. The potential as derived from these measurements however, was

very much less than expected and led us to look for a more sensitive method. Accordingly, to meet this requirement the calorimeter which we have called apparatus *D* was constructed as in Fig. 2 which proved to be very sensitive and gave better results. To obtain the best results the readings were taken in a room of nearly constant temperature and the apparatus was surrounded by a constant temperature water jacket, corrections for radiation being made here as in the previous case.

To calibrate the apparatus a continuous current of measured intensity and potential was discharged for a known length of time through the tube. Thus a known quantity of heat was developed within the tube and the rise of the mercury column produced by it was carefully measured. After correcting for radiation, it was found that a rise of one millimeter of the mercury column corresponded to 0.2049 calories of heat developed in the tube, or in other words the constant of apparatus *D* was 0.2049 calories per millimeter. A number of calibrations of this kind gave results which differed only very slightly in the third significant figure. Some of these measurements are given in Table I. together with the potential measurements taken simultaneously by means of the Braun tube. As in this case the heat in the tube was developed

TABLE I.

Calibration of Apparatus D, by means of continuous discharge, together with simultaneous potential determinations made by means of the Braun Tube.

Test No.	Potential Determinations by Means of the Braun Tube.						Heat Determinations. Calibration of Apparatus D.				
	Position of Fluorescent Spot.				Potential Derived.		Potential by Kelvin Volt Met.	Current by Wiedemann Galvanometer.	Heat Devel. by Current in 10 Min.	Rise in Hg Col. Corr. for Radiation.	Calories per mm. of Hg Column.
	For Unknown Potentials.		For Known Std. Potentials.								
	Max. x	Min. y	$V=480.$ a	$v=240.$ b	Max. X	Min. Y	Volts	Amps.	Total Cal. Q	Total Rise. h	Q_0
1	5.1	5.1	6.1	4.6	320	320	317	.000509	23.22	11.34	2.047
2	5.3	5.3	6.2	4.8	326	326	325	.000777	36.37	17.70	2.055
3	5.9	5.9	7.0	5.3	325	325	325	.000771	36.101	17.65	2.045
										Average $Q_0 = 2.049$	

by a continuous discharge in one direction, only one potential difference would exist between the electrodes and therefore only one potential value is given by the Braun tube.

III. METHOD OF DETERMINING THE LIMITS OF POTENTIAL DIFFERENCE BY MEANS OF THE BRAUN TUBE.

At the same time that the heat method was being perfected, tests were also being made by means of the Braun tube which proved to be the better method for present purposes. The method was as follows:

Potential leads connected the electrodes *AB*, Fig. 3, of the discharge tubes to the potential plates *Ab* of the Braun tube, then whenever there was a difference of the potential between *A* and *B* the same potential difference existed at *ab*, and caused a displacement of the fluorescent spot upon the screen *S*. Moreover the displacement was proportional to the potential difference and when read off on the illuminated scale which has been described, it afforded a means of measuring the potential. The potential of a constant discharge between *A* and *B* is constant, and the round fluorescent spot accordingly remains steady upon the screen at whatever point the constant potential difference places it. The varying potentials of a disruptive discharge cause rapid oscillations of the spot, which produces a thin, bright, fluorescent line upon the screen varying in length according to the potential variations at *AB*. A constant potential of two or three hundred volts or more at *AB* may cause the spot to disappear. The reason for this is that the applied potential bends the cathode rays so much that they no longer fall upon the screen. The spot or line can be brought back again, however, in a very simple manner by means of the electromagnets placed opposite the plates. The magnets should be so located that their magnetic lines of force are perpendicular to the axis of the Braun tube and parallel to the plates. Increasing the strength of the magnetic field decreases the whole deflection of the cathode ray proportionally and thus brings the spot upon the screen. If the field thus produced is uniform and constant, the displacement of the spot will still be proportional to the potential difference between the plates, though the displacement will be less than before. The deflections produced by the potential differences, as thus affected by the magnetic field, can now be calibrated by direct comparison with known potentials in the following way. The

connections given in Fig. 3 show the method of calibration used in these measurements. An upward throw of the transfer switch T_1 places the plates *ab* of the Braun tube in connection with the electrodes *AB* of the discharge tube. A downward throw places *ab* in connection with the terminals of storage battery S_2. While this is down, changing the position of the transfer switch T_2 places upon the plates *ab* either of any two standard voltages of battery S_2 which may be chosen for purposes of calibration. The best results were obtained when, for this purpose, standard voltages were selected which coincided as nearly as possible with the unknown limits to be measured. Moreover, the deflection should be calibrated for each observation at the instant that the observation is made, for the length and position of the fluorescent line varies instantly with any slight change in the vacuum conditions of the Braun tube. By means of the telescope, the limits of the fluorescent line or the position of the spot, was read upon the luminous scale, first with the Braun tube connected to the terminals *AB*, then to a known high voltage and immediately afterward to a known low voltage of battery S_2, these adjustments being rapidly made by the transfer switches T_1 and T_2. Having thus obtained the readings for the two known voltages we can calculate the unknown voltages corresponding to the other points read upon the screen at that time. The maximum and mininum voltages for any oscillation of the spot of course will be the points represented by the upper and lower ends of the fluorescent line. Thus if x and y are the readings upon the scale corresponding to the upper and lower ends of the fluorescent line, as produced by the various potentials to be measured, and if a and b denote the two points upon the scale corresponding to the two known calibration voltages, V and v, then the unknown voltages X and Y corresponding to the two readings x and y will be

$$X = (x - a)\left(\frac{V - v}{a - b}\right) + V$$

and

$$Y = (y - b)\left(\frac{V - v}{a - b}\right) + v.$$

This magnetic method of diminishing the fluorescent displace-

ment does not apply for the measurements of potential variations which exceed the limits of the fluorescent screen. Thus for example, by means of this method I could measure the potential difference between 750 and 900 volts, but could not measure the difference between 300 and 900. For if the magnetic field were made strong enough to bring the deflection corresponding to 900 volts down upon the screen, then that corresponding to 300 volts would fall below it.

For the measurements of wide variations of potential of this kind the following method of diminishing the fluorescent displacement was employed successfully. Two equal condensers *CD* and *GH* having movable plates were placed in series with the potential plates *ab* of the Braun tube, as indicated in Fig. 5. Only a fraction of the total potential then fell upon the plates *ab* and by adjusting the distances between the plates of the condensers the fluorescent displacement could be made as small as desired. Since a constant potential applied to the condensor plates *C* and *H* only produced an instantaneous effect upon the fluorescent spot, and since alternating current could not be used, the only direct method of calibration was that of rapidly interchanged applications of different positive potentials. Fig. 5 shows the connections as applied for this purpose. *F* represents an electro-tuning fork, making 100 vibrations a second and *mnop* represent mercury contacts to which the terminals of the storage battery S_2 were connected. When the transfer switch T_1 was thrown downward, the condenser plates *C* and *H* were connected to the storage battery S_2 through the mercury contacts of the tuning fork. When the tines of the fork approached each other, the circuit was opened at *op* and closed at *mn* and there was a difference of potential of say 800 volts between the plates *C* and *H*, but when the tines of the fork separated the circuit was broken at *mn* and closed at *op*, and there was a difference of potential of say 400 volts between *C* and *H*. Thus

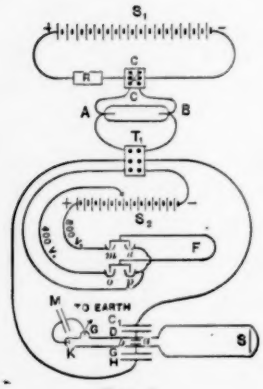


Fig. 5.

two known positive potentials were interchanged between the plates *C* and *H* 200 times each second and a known variation of potentia- was maintained between the condensor plates by means of the storage battery and tuning fork with which to compare the unknown differences of potential produced by the glow tube. Hence the interchanging known potentials as thus employed for calibration purposes were applied to the plates very much as they occurred in actual practice when coming from the discharge tube, and they produced a very definite line on the screen *S*, the maximum and minimum of which could be read very distinctly on the scale. The calibration curve given in Fig. 6 shows the variations of potential as they actually existed when the connections to the battery were made to the tuning fork in this manner, the potential development thus obtained being very different in character from those obtained from the discharge tube. By means of the tuning fork the condenser method can be applied to the Braun tube for all interrupted discharges of one direction. It can be applied without the tuning fork to all discharges of alternating directions.

Fig. 6.

IV. Method of Observing the Discharge Frequency and the Successive Stages Through which the Potential Passes in the Progress of Each Discharge.

The measurements taken by means of the Braun tube and telescope as previously described determine simply the limits of potential differences. If, however, the fluorescent images on the screen *F* be observed by means of a rotating mirror, the lines will appear as curves, or waves, as seen in the charts. In most cases the complete wave is not visible, for only the rising portion and crest can be seen, while the falling portion is invisible. Each crest denotes a single charge and the number of these seen per second determines the frequency of discharge.

Moreover the form of the rising portion that is visible shows the various stages through which the potential passes from the beginning of each charge formation until the accumulated charge is discharged between the electrodes. For the elevation of the spot upon the screen at any instant measures the potential, and the hori-

zontal projection of the line, taken in connection with the speed of the mirror, measures the duration of time required for each charge to accumulate.

Each complete period then may be considered as consisting of two distinct intervals, viz. that of charge accumulation, in which there seems to be no transmission of electricity between the electrodes, but in which the potential rises from minimum to maximum and the tube becomes charged; and that of charge transmission, in which the potential falls suddenly from maximum to minimum and the accumulated charge passes between the electrodes. This latter we may call the *true discharge*, and the mean rate at which the transmission takes place during this latter interval we have called the *true current intensity*. The true discharge takes place so rapidly that in most cases it leaves no line of light upon the mirror owing to the insufficiency of light, and the duration of the interval is denoted by a break in the visible line. The line, if seen during the true discharge, would differ but slightly from a vertical line. In a few cases such a line was actually visible faintly connecting the maximum to the minimum potential.

By means of this method, therefore, it is not usually possible to trace the potential variations which occur during the true discharge, but they can be plainly seen during the charge accumulation. It is also possible to determine with considerable accuracy both the frequency of discharge and the time required for the charge transmission, as well as to calculate the true current intensity.

Various conditions which affect the charge and discharge phenomena were examined at this time.

V. Description of Tests Made and Results Obtained.

(*a*) *Simultaneous Measurements of Potential by Means of Calorimeter and Braun Tube.*

Table II. gives the results of potential measurements of disruptive discharge made simultaneously by means of the calorimeter (apparatus *D*) and the Braun tube. The object of this series was to ascertain whether the results obtained by one method would agree with those obtained by the other, when applied to disruptive discharges. The potential measured was that produced by

the discharge between the electrodes of apparatus *D*, the vacuum being varied as indicated in the table. Column 3 of the table gives the mean voltage as determined by heat measurements, column 4 gives the corresponding potential as measured directly by means of the Kelvin multicellular voltmeter, and columns 5 and 6 give respectively the maximum and minimum voltage as obtained by the Braun tube measurements, while column 7 is the numerical mean of 5 and 6.

It will be seen from this that the potentials obtained by the calorimeter method are very nearly the same as those obtained by the Kelvin voltmeter. The differences may be accounted for perhaps,

TABLE II.

Potential of Disruptive-Discharge, as Determined Simultaneously by Means of Calorimeter and Braun Tube.

Test No.	Air Pressure in mms.	Galv. Deflection $\times .38 \times 10^{-6}$	Potential Determined by Means of				
			Calorimeter App. D.	Kelvin Voltmeter.	Braun Tube.		
					Max.	Min.	Mean.
	1	2	3	4	5	6	7
1	4.9	1.05	391	381	416	224	320
2	1.8	2.15	418	425	544	240	392
3	1.7	2.22	401	417	480	223	352
4	1.7	2.23	406	413	480	240	360
5	1.7	1.75	400	413	480	225	352

by errors in measurement. They also lie between the maximum and minimum values obtained by the Braun tube, as would naturally be expected, but they are much larger than the numerical mean given in column 7. So great a difference as this cannot be attributed to errors of measurement, especially since the difference is always in the same direction. It may be remarked, however, that according to the potential curves, given later, the numerical mean of the maximum and minimum would probably be less than the actual mean. But the most important point to be noticed in these results is the fact that the potential never even approaches zero, but falls to a minimum only, which remains constant for the particular condition under which the test is made. The conditions of test seem to affect both the minimum and maximum potentials. This is referred to again later. The Braun tube method made it

possible to examine the phenomena in tubes of many forms and under many conditions which would not have been possible by means of the calorimetric method. Having reason for believing that the character of discharge was not the same for all tubes nor the same for any one tube under all different conditions, we made tests on various kinds of tubes, some of which are represented in Fig. 4, and varied the conditions for each different tube.

(*b*) *To Test the Effect Produced by Changes in Resistance and Air Pressure.*

Chart I. gives the results of a characteristic series of tests made upon discharge tube E for the purpose. The connections are represented in Fig. 3. The discharge was produced by a current from storage battery S_1 of 1,040 volts. A liquid rheostat R of very high resistance was placed in series with a tube AB; experiments proved that by varying the amount of this resistance the character of the discharge could be entirely changed. With a small resistance the discharge was always continuous and the image upon the fluorescent screen was a small round spot fixed in its position. For such conditions the curve in the mirror was seen to be a horizontal straight line at some definite constant potential, as represented in Chart I., tests number 1, 7, 8, 14 and 19. With a large resistance, however, the discharge became disruptive and the fluorescent image upon the screen was a thin vertical line varying in length according to the difference between the maximum and minimum potentials in the glow tube. Tests 3 to 6 are good examples of this. Accordingly tests were made with various resistances while the pressure was kept constant as shown in tests 1 to 8 inclusive. Then with a different air pressure the tests were repeated with the same series of resistances as nearly as possible, (see tests 7 to 13 inclusive). This was repeated for a number of different air pressures. In every case the potential measurements were first made and immediately afterward the curves were observed in the rotating mirror. In this way the potential limits were determined and the character of the discharge was plainly seen as to whether it was continuous or disruptive, and if disruptive, how great was the frequency and what stages of development the potential passed through at every

CHART I.

Changes in Resistance and Air Pressure.

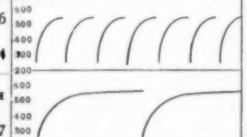
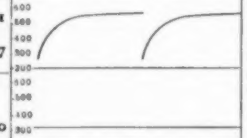
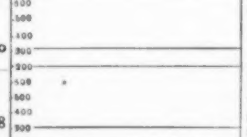
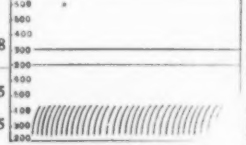
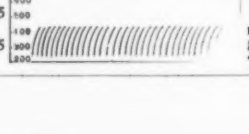
Test No.	Air Pressure.	Resistance in Circuit.	Galv. Defl. $K = 21 \times 10^{-6}$	Max. and Min. Volts of Curves.	Potential Curves for Each Test, Representing Form, Amplitude and Approx. Relative Frequency.	Remarks.
1	2	3	4	5	6	7
1	3	1	21.3	284		Apparently a continuous discharge. Is stable and no breaks are visible in the line.
2	3	2	15.5	458 280		Unstable discharge. Fluctuates between continuous and disruptive, without change in external resistance. The glim is longest when the discharge is disruptive
3	3	3	8.9	488 270		Stable disruptive discharge. Discharge lines are distinct in mirror, but too numerous to count. Have form as here given
4	3	4	5.8	535 260		Frequency not so great as in Test 3, but greater than in Test 5.
5	3	5	3 4	556 264		Character of curves in Test 5 seems to be the same as in former tests. Seven lines visible in the mirror.
6	3	6	3.3	561 267		Only two lines can be seen in the mirror at a time in Test. 6, though in Test 3 they were too numerous to count.
7	1.07	1	12.6	320		The external conditions in Test 7 are the same as in Test 1, but the air pressure is less here. Discharge stable and continuous. Glim is very short.
8	1.07	2	8.5	328		Discharge is unstable in Test 8 Fluctuates between continuous at 328 volts and disruptive discharge with min. at 245 and max. at 435 volts. Tests 8 and 9 are practically the same test, the discharge fluctuating spontaneously from one form to the other.
9	1 07	2	7.5	435 245		The glim in 8 is short, but in 9 it nearly covers the cathode. Tests 8 and 9 seem to correspond to Test 2, but with less air pressure.

CHART I.—*Continued.*

Changes in Resistance and Air Pressure.

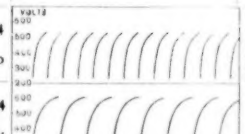
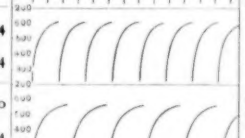
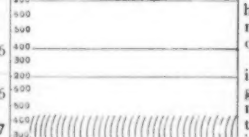
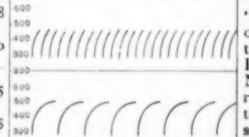
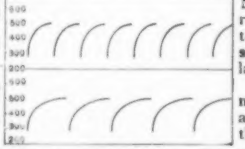
Test No.	Air Pressure.	Resistance in Circuit.	Galv. Defl. $K = 21 \times 10^{-6}$	Max. and Min. Volts of Curves.	Potential Curves for Each Test.	Remarks.
1	2	3	4	5	6	7
10	1 07	3	6.3	534 240		Stable disruptive discharge. The frequency here is less than in Test 9, and the amplitude is greater.
11	1.07	4	3 8	604 224		
12	1 07	5	2.4	560 224		The glim light does not cover the cathode in Tests 7 to 13 inclusive
13	1.07	6	2.0	592 216		In Test 13 the curves have a decided curl upward at the lower limit, but no connecting line is visible between the upper end of one curve and the lower end of the next
14	0 52	1	10.8	376		In Test 14*a*, hazy continuous horizontal band is seen in the mirror, with constant potential of 376 volts.
15	0.52	2	8 3	436 297		Stable disruptive discharge in Test 15. Frequency too great to count the lines in the mirror. Glim does not cover the cathode in Tests 14 to 18 inclusive.
16	0.52	4	3 8	458 290		The numerals in column 3, "Resistence in Circuit," indicate the amount of resistance that is placed in series with Battery S and the glow tube. No. 1 signifies the smallest resistence that can be obtained by the Liquid Rheostat, while No. 8 denotes the largest amount.
17	0.52	5	1.6	495 285		
18	0 52	8	0.4	500 283		The intervening numbers denote relatively proportional amounts. This applies throghout all the tests.

CHART I.—*Concluded.*

Changes in Resistance and Air Pressure.

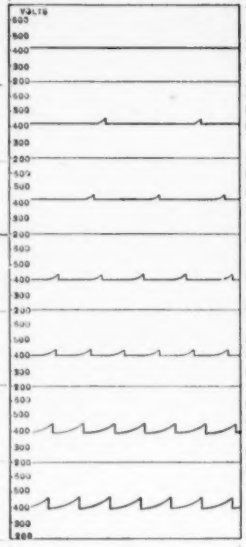
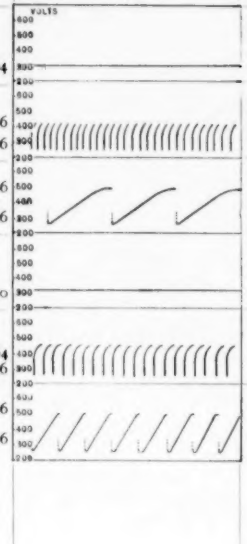
Test No.	Air Pressure.	Resistance in Circuit.	Galv. Defl. $K = 21 \times 10^{-6}$	Max. and Min. Volts of Curves	Potential Curves of Each Test.	Remarks.
1	2	3	4	5	6	7
19′	0.25	6	1.4	426		The glim light is short Stable continuous discharge. As the resistance in the liquid rheostat is gradually increased from Resistance 6 in Test 19′ to Resistance 7 in Test 20′, the curves undergo the following changes as seen in Test 19′, 19″, 19‴ and finally Test 20′ where the potential was again measured. As the resistance is gradually increased from Resistance 7 to Resistance 8 the interruptions become more frequent and the max. potential rises slightly. See 20″ and 20‴. With this low air pressure (0.25) the character of discharge as seen in Tests 19′ to 21 is quite different from that of greater air pressure as seen in Tests 1 to 18 inclusive. Resistance 8 = two high-resistance liquid rheostats, are in series. A fine discharge-line is seen in all of these tests (19′ to 21) connecting the max. to the min. potential. In all other parts the band is broad. The glim covers the cathode in Tests 20′ to 21 inclusive, but not so in the previous tests.
19″	"	6+	"			
19‴	"	6++	"			
20′	"	7	1.4	448 408		
20″	"	7+				
20‴	"	7++				
21	"	8	0.3	476 408		

CHART II.

Changes in Capacity and Air Pressure. Tests all made at the Critical Point.

Test No.	Air Pressure.	Resistance in Circuit.	Condenser.	Galv. Defl. $K = 42 \times 10^{-6}$	Max. and Min. Volts of Curves.	Potential Curves for each Test, Representing Form, Amplitude and Approximate Relative Frequency.	Relative Freq'cy.	Remarks
1	2	3	4	5	6	7	8	9
22′	0.53	3	Out	4.7	304		*	Continuous discharge which changes spontaneously to disruptive or vice versa. This condition we have called the "Critical Point" When the condenser is "out" (not connected) the discharge is as seen in Test 22′ or 22″, but when the condenser is "in" (is connected) the discharge becomes that of 22‴. The ratio of frequency in 22″ to that in 22″ is 10 to 1. When the air pressure is reduced to 0.30 mm the discharge at Critical Point becomes that of Test 23′, 23″ and 23‴. The ratio of frequency in 23″ to that of 23‴ is 10 to 4. The glim light in 22‴ and 23‴ covers the cathode, but, not so in the other cases Notice the decided curl upward at the lower limit of the curves in Test 22‴ and 23‴.
22″	"	"	Out	4.0	416 256		30	
22‴	"	"	In	4.4	496 256		3	
23′	0.30	4	Out	7.0	320			
23″	"	"	Out	6.5	464 256		20	
23‴	"	"	In	6.3	496 256		8	

discharge. The mirror was rotated as nearly as possible with uniform speed so that the relative frequency in the various tests was approximately seen. In the charts each horizontal space (except the one at the top) which we have called a horizontal "row" is devoted to a single test, and the test to which it is devoted is indicated by the numeral at the left. The vertical spaces we have called "columns" and each column is devoted to some particular phase of each respective test. The horizontal row at the top of the page tells what particular phase of the test each column is devoted to. Thus in Chart I., column number 1 tells the number of the test to which each row is devoted, and column number 5 gives the maximum and minimum potential obtained in each test, while column number 6 represents the potential curves for that test. Thus column number 5 shows that the curves of column number 6, test number 3, begin at a minimum of 270 volts and rise to a maximum of 488 volts, and the form of the curves in column number 6 shows the stages through which the potential passes. The curves are drawn on a scale which is common to all tests, the ordinates denoting potential and the abcissas denoting time. For want of space the potential from zero to 200 volts has been omitted from the charts, since in the tests the minimum potential was never found to fall below 200 volts. The bottom ordinate in each test-chart, therefore, denoted 200 volts, while the top one represents 700 volts. As nearly as possible the curves in each row represent the discharge lines as actually seen in the mirror both in form and relative frequency. The numbers in column number 5 then denote the upper and lower potential limits as measured by the curves in the same horizontal row in column number 6 and the number of lines drawn in the row in column number 6 denotes the relative frequency of discharge for that test, the mirror being kept as nearly constant as possible throughout.

Among the things learned from the experiments represented in Chart I. in which the resistance in the external circuit was varied, while other conditions remained unchanged, was the fact that a change in external resistance will change the character of discharge from continuous to disruptive or *vice versa* and also that there is one point where the resistance can be such that the discharge will

fluctuate spontaneously from continuous to disruptive or *vice versa* without any external change in resistance; this may be called the critical point and is apparently the only condition that can be reproduced from time to time with approximate certainty.

(*c*) *To Test the Effect Produced by Changes in the Capacity of the Circuit at Various Air Pressures.*

Having reasons to believe that the character of discharge was altered by changes in capacity, experiments were made to test the supposition. For this purpose tube *F*, Fig. 4, was used in the same manner as *E* was used in the preceding experiments, except that the plates of a Kohlrausch condenser were connected to the electrodes of the tube by means of a switch in such a way that they could be connected or disconnected, quickly, at pleasure, without changing the speed of the rotating mirror. The tests were made at the critical point. That is while the charge was continuous and the condenser was disconnected (out), the external resistance was gradually increased until the critical point was reached and the measurements made, then the measurements were repeated with the condenser connected (in), the speed of the mirror being kept constant. The change in potential was easily determined and the character of the curves observed. Characteristic results are given in Chart II.

(*d*) *Changes in Capacity and Distance Between the Electrodes.*

To test the effect of variations in capacity and distance between the electrodes, measurements were made upon tube *H*, Fig. 4. This tube was so constructed that by applying a magnet externally to the iron portion *b* of the electrode *ac* the distance *cd* between the electrodes could be made any desired length. Results of a characteristic series of measurements are given in Chart III. All tests were made at the critical point, and with the exception that the resistance in the circuit had to be increased a little to produce the critical point, when the electrodes were further apart, the conditions were alike in all corresponding tests. The air pressure was one millimeter throughout the series.

CHART III.

Changes in Capacity and Distance Between the Electrodes.
All Tests Made at Critical Point on Tube H.

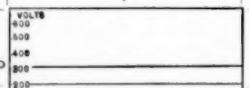
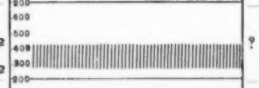
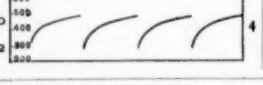
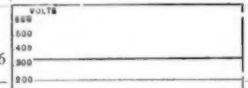
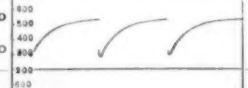
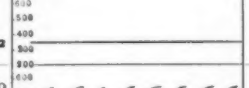
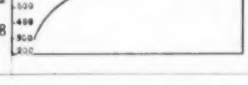
Test No.	Distance Between Electrodes in Cms.	Condenser.	Galv. Defl. $K = 42 \times 10^{-6}$	Resistance.	Max. and Min. Volts of Curves.	Potential Curves for Each Test, Representing Form, Amplitude and Approx. Relative Frequency.	Frequency.	Remarks.
1	2	3	4	5	6	7	8	9
24′	2	Out	18.1	3—	320			Glim light covers about $\frac{1}{16}$ of cathode. Discharge fluctuates at critical point as seen in 24′ and 24″. Glim covers about ½ cathode in 24″.
24″	2	Out	17 5	3—	432 272		?	Lines too numerous to count in 24″. Glim covers entire cathode and only 5 lines visible in 24‴.
24‴	2	In	16 9	3—	470 290		5	Discharge changes from 24″ to 24‴ spontaneously, simply by connecting "in" the condenser.
25′	5	Out	15.3	3	334			Glim covers about $\frac{1}{18}$ of cathode in Test 25. Test 24 differs from Test 25 respectively only in cms. distance between electrodes
25″	5	Out	14.2	3	456 278		?	Glim covers ½ of cathode. Lines too numerous to count
25‴	5	In	14.2	3	490 292		4	Discharge changes from 25″ to 25‴ spontaneously, and from 25″ to 25‴ by connecting "in" the condenser. Glim covers entire cathode and only 4 lines visible in 25‴.

CHART III.—*Concluded.*

Changes in Capacity and Distance Between the Electrodes.
All Tests Made at Critical Point on Tube H.

Test No.	Distance Between Electrodes in Cms.	Resistance.	Condenser.	Galv. Defl. $K = 42 \times 10^{-6}$	Max. and Min. Volts of Curves.	Potential Curves for Each Test, Representing Form, Amplitude, and Approx. Relative Frequency.	Frequency.	Remarks.
1	2	3	4	5	6	7	8	9
26′	10	3^{+}	Out	13.8	336			Glim light covers $\frac{1}{16}$ of the cathode in 26′.
26″	10	3^{+}	Out	13.1	512 272		40	Glim covers about ½ of the cathode in 26″ and 40 lines are visible in the mirror.
26‴	10	3^{+}	In	12 4	530 290		3	Glim covers the entire cathode in 26‴ and 3 lines are visible in the mirror.
27′	20	3^{++}	Out	7 1	352			Glim covers about ½ of the cathode in 27′.
27″	20	3^{++}	Out	5 7	560 272		8	Glim covers about $\frac{7}{16}$ of the cathode in 27″ and 8 lines are visible in the mirror
27‴	20	3^{++}	In	5 0	672 288		1	Glim covers entire cathode in 27‴ and one line is visible in the mirror A decided upward turn is seen at lower limit of curve.

(e) Comparison of the Phenomena of Positive and Negative Discharge with Reference to Frequency and Capacity.

Professor G. Wiedemann found (Elektricetät von G. Wiedemann, 4, p. 459), that with the current from an influence machine, and therefore of uniform intensity, the frequency was greater when the negative electrode was free and the positive connected to earth, than when the positive was free and the negative was connected to earth. That is to say, with uniform current a negative discharge gave a greater frequency than the positive. From this he assumed that the voltage varies inversely as the frequency, on the assumption that

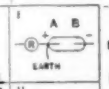
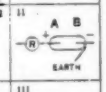
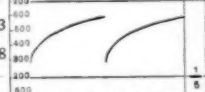
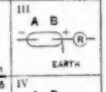
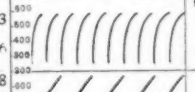
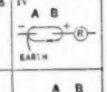
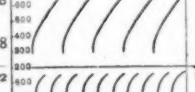
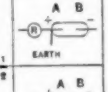
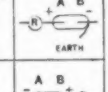
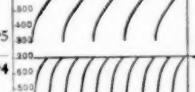
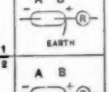
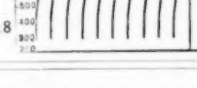
$$n = \frac{I}{CV}.$$

In other words that, if the frequency is decreased one half, the voltage should be doubled. This assumption must be true, of course, if the capacity remains constant. Professor E. Wiedemann and others have, at various times, obtained results some of which verify this law of frequency and some contradict it, and no satisfactory reason has been given for the discrepancy. Professor E. Wiedemann has suggested that perhaps the capacity does not remain constant. To ascertain whether this can be the case or not, two series of tests were made. Results of the first series are given in Chart IV. while those of the second are given in Chart V.

In both series the current was kept constant in all cases and no changes were made, except that of reversing the current through the tube and interchanging the earth connection. The connections for the first series are as shown in Fig. 3 with the exception that the earth could be instantly connected to the electrode A or B of the glow tube at pleasure by means of an independent switch. In this series four combinations were possible as shown by I., II., III. and IV. in column 8 of Chart IV., where R in column 8 denotes the liquid rheostat as indicated by R of Fig. 3, in series with the battery S_1 and discharge tube AB. In I. and II. the direction of the current was unchanged while the earth was connected first to A and then to B. In III. and IV. the current was reversed in direction while the earth was again connected first to A and then to B. With these combinations it was found that the frequency obtained

CHART IV.

To Test the Effect of Interchanging the Earth Connection, i. e., to Compare the Phenomena Produced by a Negative Discharge, with that Produced by a Positive, the Tests Being on Tube F, with 2.8 mm. Air Pressure.

Test No.	Distance Between Electrodes in cms.	The Negative Charge is on	The Negative Electrode is	Max. and Min. Volts of Curves.	Potential Curves for Tests, Representing Form, Amplitude and Approx. Rel. Frequencies.	Ratio of Frequencies	Plan of Tube Connections.	Remarks.
1	2	3	4	5	6	7	8	9
28′	10	B	Free	603 309		1		No condenser was used in these tests. A medium resistance was used in series and left constant throughout. The only changes made were the interchanging of the earth connection and the reversing of the current.
28″	"	B	Earthed	597 276		2		
29′	"	A	Free	603 298		1		
29″	"	A	Earthed	593 256		6		
30′	40	B	Free	688 288		1		
30″	"	B	Earthed	672 270		2		
31′	"	A	Free	670 305		1		
31″	"	A	Earthed	704 278		2		

from the positive electrode, as in II. and IV., was always very much greater than from the negative electrode as in I. and III. These results are therefore directly opposite to those obtained by G. Wiedemann and are not in accordance with his law of frequency, for although the frequency is doubled in some cases the potential varies very little, if at all. It will be noticed, however, that in I. and III. the earth connection is made between the tube and the rheostat, while in II. and IV. it is not. It is possible therefore that the position of the rheostat may produce the change in frequency by changing the capacity of the circuit.

In the next series of tests the combinations were modified to avoid this difficulty. Fig. 7 shows the plan of connection for the second series and the four possible combinations are indicated in V., VI., VII. and VIII., column 10 of Chart V. The tests in this series were made as follows:

First two measurements were made with unchanged connections as in V. and VI., but with the direction of the current reversed in one of them, so that in V. there was a negative discharge from A while in VI. there was a positive discharge from the same terminal, all other conditions being unchanged. Then all of the circuit connections, except those connecting to the Braun tube, were removed from A and B and interchanged in position. That is, the connecting wire p was removed from A and connected to B while the wires m and n were removed from B and connected to A. With these interchanged connections two more measurements were made as before with the current first in the direct and then in the reverse direction through the tube. In other words in VII. there was a positive discharge from B while in VIII. there was a negative discharge from the same electrode, all other conditions being the same. Hence, VII. and VIII. are exactly the same as V. and VI., respectively, except that the discharge proceeds from the opposite electrodes. If then, there is any difference between the frequencies obtained in these four cases, or if the potential in any case is greater than in another it must be due, either to some difference in the electrodes, or to some intrinsic difference in the character of the positive and negative discharge. Apparently the difference does not lie in the electrode, for interchanging the terminals does not seem to produce any different effect. An examination of Chart V. will show, however, that in all cases, whenever the discharge is negative the frequency is decidedly greater than when the discharge is positive. This is in agreement with G. Wiedemann's results, but the law of frequency does not seem to be verified in this series, for if

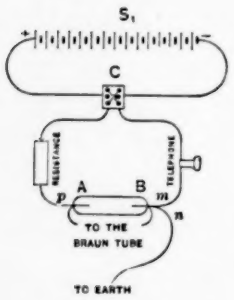
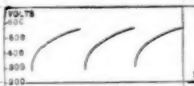
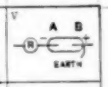
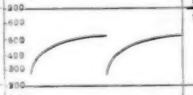
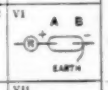
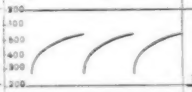
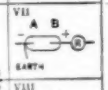
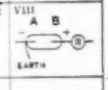
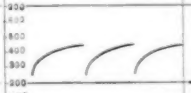
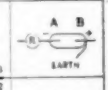
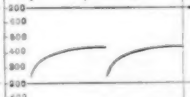
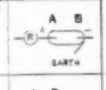
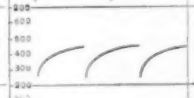
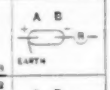
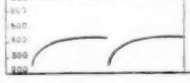
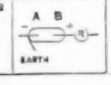
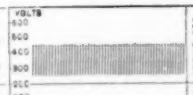
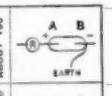
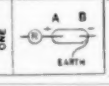


Fig. 7.

$$n = \frac{I}{CV}$$

CHART V.

To Test the Effect of Changing the Earth Connection, i. e., to Compare the Phenomena Produced by a Negative Discharge with that Produced by a Positive; 1st, With Changes in Air Pressure; 2d, With Changes in Resistance, and 3d, With Changes in Capacity. All Tests made on Tube F.

Test No	Resistance in Circuit.	Condenser.	Air Pressure.	The Negative charge is on	The Negative Electrode is	Max. and Min. Volts of Curves.	Potential Curves for Tests, Representing Form, Amplitude and Approximate Relative Frequencies	Frequencies	Plan of Tube Connections.	Ratio of Max. Voltages.	Remarks.
1	2	3	4	5	6	7	8	9	10	11	12
32′	3	Out	3.8	A	Free	560 274		3		$\frac{560}{526} = 1.06+$	
32″	3	Out	3.8	B	Earthed	526 274		2			
33′	3	Out	3.8	B	Free	547 266		3		$\frac{547}{573} = 0.94$	
33″	3	Out	3.8	A	Earthed	573 266		2			
34′	3	Out	1.21	A	Free	449 245		3		$\frac{449}{443} = 1.01$	
34″	3	Out	1.21	B	Earthed	443 245		2			
35′	3	Out	1.21	B	Free	449 251		3		$\frac{449}{437} = 1.03$	
35″	3	Out	1.21	A	Earthed	437 251		2			
36′	2	Out	1.8	B	Earthed	449 267		ABOUT 150			The frequency in 36′ is too great to count and can only be estimated, but is plainly greater than it is in 36″ which is estimated at 100.
36″	7	Out	1.8	B	Earthed	481 256		ABOUT 100			
36‴	"	In	1.8	B	Earthed	688 309		ONE			Only one line in the curve is visible in the mirror in test 36‴.

is true, when the current is uniform, then if C is constant, n should vary inversely as V, which does not seem to be the case in these results. If the potential changes at all, it seems to increase with the

frequency rather than otherwise. At any rate, even after making full allowance for errors in measurement, the potential does not vary inversely as the frequency. This, then seems to indicate that the capacity of the tube does not remain constant.

VI. OBSERVATIONS AND CONCLUSIONS DERIVED FROM THE RESULTS.

Facts which may be noticed by examining the charts, combined with the phenomena noticed in the progress of these investigations may be condensed into the following observations:

From Chart I. it may be noticed:

1. With sufficiently low resistance in the circuit the discharge is continuous, but when the resistance is increased sufficiently the discharge suddenly becomes disruptive; the frequency of discharge continues to decrease, and the maximum potential to increase, from that point on as the external resistance is increased.

2. If the low resistance, at which the discharge is continuous, is increased very slowly, a critical point may always be found where the discharge fluctuates between the continuous and disruptive form without any change in the external circuit. Simply touching with the finger a point here or there in the external circuit is sufficient to cause the discharge to change back or forth from one form to the other, or the change may occur without any point being touched, or without any external variation whatever being made. This apparent spontaneous fluctuation is probably due to slight changes in the capacity of the external circuit, which is very easily affected. The tests which follow seem to indicate this.

3. The glim light is always longer when the discharge is disruptive than when it is continuous. This is true even at the critical point. But the true current intensity is greater for disruptive discharge than for continuous and, as already known, the glim is always longer the stronger the current. These observations have been noticed in course of the experiment although the facts have not been so stated before.

4. The potential never falls to zero nor even near it but varies between a maximum and minimum at each interruption. Plotting the potential curves with the potential, as ordinates and the time as abcissas, it is seen that from the minimum point the potential at

first rises very abruptly, but as it approaches the maximum, especially in discharges of low frequency, the increase occurs but slowly and the curve becomes nearly a horizontal line near the upper potential limit. When the potential has fully reached the maximum it falls off so quickly that the path of the fluorescent spot upon the screen usually becomes invisible in the mirror. This sudden drop in potential evidently denotes the instant at which the real discharge between the electrodes takes place. The potential develops as it does when a condenser is charged until the discharge potential is reached. Apparently the discharge takes place only after the walls of the tube have been fully charged. That is, there is a silent discharge from the free electrode to the walls of the tube which gradually raises the potential. Then when the maximum potential is fully reached there is a sudden discharge from the walls and from the free electrode to the electrode which is connected to the earth. Such a manifestation was formerly observed in the like phenomena examined by E. Wiedemann and Lehmann. In this manifestation may be found the reason for the results of G. Wiedemann concerning the difference between positive and negative discharges, in which the existing velocity of the negative electrons plays an important part. That the potential drops suddenly the instant the discharge sets in, is in agreement with the results which Hittorf has previously found, namely, that it requires a higher potential to begin a discharge than to maintain it.

5. With the discharge proceeding always from the same positive or negative terminal, it is seen that as the frequency of discharge decreases the limits of potential differ more widely, the maximum potential increasing greatly while the minimum limit seems to drop slightly. Or conversely, the greater the current intensity, that is, the greater the number of discharges per second, the smaller the amplitude of potential variation becomes. The reason for this is that the shorter the time interval existing between discharges the greater is the number of free electrons then in the tube, and accordingly the greater the conductivity of the gas. From this it follows that there can be no definite fixed discharge potential or normal potential for disruptive discharges, but the value will vary with every varying condition that may exist.

6. In some cases, especially in Chart II., an upward turn is distinctly seen at the lower limit of the curve. That is to say, as the fall in potential approaches the lower limit the fluorescent line gradually becomes visible and when the minimum is reached, the bend from a downward to an upward direction is clearly seen. This plainly indicates the direction of the curve in the invisible portion, and shows that the potential does not fall at any time below the so called minimum. In other words, the potential drops most rapidly near the maximum and then more slowly until it reaches the lower limit, when it begins to rise again. The change in the curve from a downward to an upward direction, so clearly seen at the minimum point, plainly indicates the lowest limit of potential. This is also verified by the fact that the mean potential obtained by heat measurements and by direct voltmeter measurements as seen in Table II. lie between the maximum and minimum potential limits.

7. The minimum potential of disruptive discharge is seen to be lower than the constant potential of continuous discharge. This indicates that there are more free electrons in the gas during the instant of actual transmission in disruptive discharge than at any time during the continuous. This makes the conductivity greater and consequently the minimum potential lower in the former case than in the latter. In other words it indicates that the true current intensity during the short periods of active transmission in disruptive discharges is greater than the current intensity of a continuous discharge. In like manner it is seen from Charts I. to III., inclusive, that within limits, as the air pressure within the tube is decreased the potential of continuous discharge is increased.

8. The results given in Charts II. to III. show also that as the capacity of the tube is increased the maximum potential of disruptive discharge is raised and the minimum is lowered; also, the frequency is diminished.

9. As the air pressure is decreased the capacity of the tube is increased. This seems to be true, for in tests which were alike in all respects, except in air pressure, the results indicate that the tube had a greater capacity with a high vacuum than it had with a low one. An example of this is seen in tests 22″ and 23″, Chart II.

in which the air pressure was 0.5 mm. in the former and 0.3 mm. in the latter. Now, if C, I. N and V denote respectively capacity, current intensity, frequency and potential, then

$$\frac{C_1}{C_2} = \frac{I_1 N_2 V_2}{I_2 N_1 V_1}.$$

Supplying the corresponding values obtained in 22″ and 23″ we have

$$\frac{C_1}{C_2} = \frac{4 \times 20 \times 464}{6.5 \times 30 \times 416} = \frac{1}{2.2} \text{ nearly.}$$

That is, the tube has a greater capacity when the air pressure is small than when it is larger.

10. Results given in Chart III. show that the potential of continuous discharge rises slightly as the distance between the electrodes increases, as would be expected.

11. As the distance between the electrodes is increased the frequency of discharge decreases and the maximum potential increases. In other words, increasing the distance between the electrodes seems to have the effect of increasing the capacity of the tubes.

12. It is seen from these measurements that the minimum potential is not affected either by changes in capacity or distance between the electrodes.

13. Results given in Chart V. show that, other things remaining the same, the negative discharge has a higher frequency than the positive, though Chart IV. shows that the external circuit may easily be modified so that the positive discharge will have a higher frequency than the negative. In other words, the character of discharge within the tube is so intimately related to every external condition of the circuit, that any apparently slight modification without may entirely change the phenomena within. This being true the discrepancies between the results of G. and E. Wiedemann may easily be accounted for on this basis.

14. The results given in Chart V. do not verify the law

$$n = \frac{I}{CV},$$

since the potential does not in any case vary inversely as the fre-

quency. On the other hand, they show that the capacity is not a constant quantity, but is different when the discharge is negative from what it is when the discharge is positive. Perhaps the explanation of this may be found in the difference that exists between the velocities of the positive and negative electrons.

15. In sending a disruptive current through a vacuum tube each period seems to consist of two very short intervals, the interval of charge accumulation and that of charge transmission. During the first interval the electrodes and walls of the tube become charged while the voltage rises from the minimum to the maximum potential. The various stages through which the potential passes during this first instant is denoted by the curved line as seen in the mirror, the first portion of which gradually curves away from the vertical and the latter portion is nearly horizontal. During the second interval, or instant, the true transmission of electricity takes place and is denoted by the break in the line indicating the drop in potential, as the voltage falls from maximum to minimum. The second interval is very short compared with the first. In other words, the time required for the true transmission of electricity between the electrodes is only a very small fraction of the total period. Apparently it is possible here to measure the duration of each interval, that is, not only to determine the frequency and time required for the charge to accumulate and the voltage to rise, but also to determine the duration of time required for the actual passage of electricity between the electrodes and the mean actual current intensity during that instant. Further tests are in progress for deriving these values.

WESTERN UNIVERSITY OF PENNSYLVANIA,
ALLEGHENY, PA., Jan., 1904.

ON THE USE OF NICKEL IN THE CORE OF THE MARCONI MAGNETIC DETECTOR.

By Arthur L. Foley.

THE magnetic detector of electric waves, described and used by Marconi,[1] consisted of a "core or rod of thin iron wires on which were wound one or two layers of thin insulated copper wire. Over this winding insulating material was placed, and over this again, another longer winding of thin copper wire contained in a narrow bobbin." One terminal of the inside winding was connected to earth, the other to an elevated conductor. The ends of the outside winding were connected to a telephone. A horseshoe magnet, suitably placed, was moved by clock work so as to cause a continuous change or successive reversals, of the magnetism of the iron core. Electric oscillations of suitable period appeared to reduce the effects of magnetic hysteresis, hence the magnetism of the iron core increased or decreased suddenly with each spark of the transmitter, inducing a current in the outer winding connected to the telephone. Marconi had (June, 1902) used this apparatus for some months in the reception of wireless telegraph messages over a distance of 152 miles, and with less power employed at the transmitting station than would have been required had he used a reliable coherer instead of the magnetic detector.

Marconi noticed that "the signals in the telephone are weakest when the poles of the rotating magnet have just passed the core and are increasing their distance from it, whilst they are strongest when the magnet poles are approaching the core." To obtain more definite results on this point I arranged to use a ballistic galvanometer instead of a telephone, and to take readings for various determined positions of the magnet and core.

The core, which was 5 cm. long, consisted of twenty-six pieces of annealed piano wire, .063 cm. in diameter. Over this was wound

[1] Note on a Magnetic Detector of Electric Waves, by G. Marconi. Proceedings of the Royal Society, Vol. LXX., No. 463, July 29, 1902.

a single layer of two-hundred turns of silk insulated copper wire No. 36, giving a total diameter core and coil of approximately .4 cm. One end of the coil was connected to a vertical wire 200 cm. long, the other end was put to earth.

The outer or secondary coil, consisting of one thousand turns of No. 30 copper wire, was wound on a wooden spool of such dimensions that the coil itself was 1.7 cm. long and .6 cm. in diameter (inside). The terminals of this coil were connected to a Rowland D'Arsonval galvanometer through a key arranged to short circuit the galvanometer after each throw of the needle. This brought the needle to rest very quickly, and permitted the position of the magnet to be changed without effecting the galvanometer.

The induction coil (one inch) of the transmitter was operated by a storage cell and was adjusted to give a 2-mm. spark between two small brass spheres, one connected to a vertical wire 200 cm. long, the other to earth. The distance between the transmitter and receiver was varied from two meters to twenty meters. The results given in this paper were obtained when the distance was made five meters. No effort was made to "tune" the circuits.

The magnet was made from a bar of steel 1.6 cm. square and 37 cm. long, bent so as to make a horse-shoe magnet about 16 cm. long with parallel legs 4.8 cm. apart. The primary and secondary coils were fastened in place on a board grooved and graduated so that the magnet could be slid back and forth in the same horizontal plane with, and in a direction at right angles to, the iron core, and placed at any desired distance from it. The graduations extended from 0 to 12 cm. zero distance corresponding to contact between the ends of the magnet and the core.

To get a reading, the galvanometer was first short circuited and the magnet placed in position. The short circuit was then broken, the transmitter operated as long as the deflection of the needle was increasing, and the throw observed.

Table I. gives the throws of the galvanometer for the given distances between the magnet and core:

A. When the magnet is placed 10 cm. from the core and moved one space nearer each successive reading.

B. When the magnet is placed in contact with the core and is moved one space farther from it each reading.

C. When the magnet is removed some distance after each reading and the transmitter operated before the magnet is placed in position for another reading.

D. When the magnet is turned over (the field reversed) between readings.

TABLE I.

Distance.	*A*	*B*	*C*	*D*
0.0 cm.	2.0 cm.			7.6 cm.
0.5	2.3	0.8 cm.	4.0 cm.	7.9
1.0	2.0	.9	3.2	6.1
2.0	1.3	1.0	2.0	3.5
3.0	.4	.9	1.2	1.6
4.0	.3	1.0	1.0	1.1
5.0	.2	.6	.5	.8
6.0	.1	.4	.3	.6
7.0	.0	.3	.2	.4
8.0	.0	.2	.2	.3
9.0	.0	.2	.1	.25
10.0	.0	.1	.1	.2

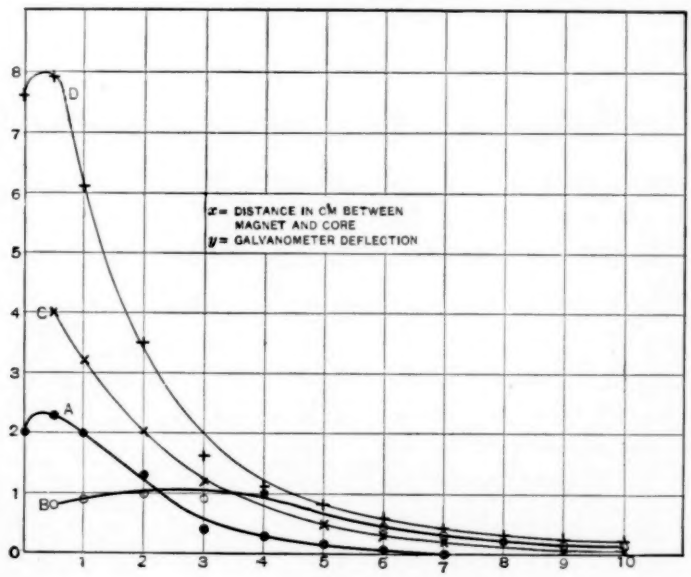


Fig. 1.

The data of Table I. are plotted in Fig. 1. A comparison of curves *A* and *B* shows that the sensitiveness of the magnetic detec-

tor depends upon both the distance and direction of motion of the moving magnet. When the magnet is near the core the detector is more sensitive when the magnet is approaching, but when some distance from the core the detector is more sensitive when the magnet is receding. Both curves indicate a maximum of sensitiveness at a distance from the core, the distance being less when the magnet is approaching than when receding.

Removing the magnet and operating the transmitter tended to demagnetize the core. Then when the magnet was placed in position and the transmitter again operated as in curve *C*, there was a relatively greater change in the magnetism of the core than was obtained under the conditions of curves *A* and *B*. Hence the deflections in column *C* are greater than those in *A* or *B*. It is evident that the relative change in the magnetization of the core would be greater still where the magnetic field is reversed after each reading, as in curve *D*.

Since nickel is more susceptible than iron in weak magnetic fields, and less susceptible in strong fields, it occured to the writer that a more uniform sensibility for varying distances between the moving magnet and core might be obtained by making the core of nickel.

Four cores were made, each one being 5 cm. long, approximately .4 cm. in diameter, and being wound with two hundred turns of No. 36 copper wire.

Core 1 consisted of 26 pieces of piano wire, .063 cm. in diameter.

Core 2 of 10 pieces of piano wire and 10 pieces of nickel wire, .082 cm. in diameter.

TABLE II.

Distance.	Core 1. Fe.	Core 2. Fe & Ni.	Core 3. Fe & Ni.	Core 4. Ni.
0 cm.	7.6 cm.	10.2 cm.	7.5 cm.	6.1 cm.
.5	7.9	9.5	7.5	9.0
1.0	6.1	8.0	7.2	8.9
2.0	3.5	4.6	4.0	4.7
3.0	1.6	3.0	2.0	1.35
4.0	1.1	1.7	1.0	0.7
6.0	0.6	0.5	0.4	0.35
8.0	0.3	0.2	0.2	0.2
10.0	0.2	0.1	0.1	0.1

Core 3 of 2 pieces of piano wire and 13 pieces of nickel wire.

Core 4 of 14 pieces of nickel wire.

Table II. gives the deflections at various distances between the magnet and each of the four cores, the magnet being moved one space at a time and having its poles reversed after each reading. The data for three of the cores are plotted in Fig. 2.

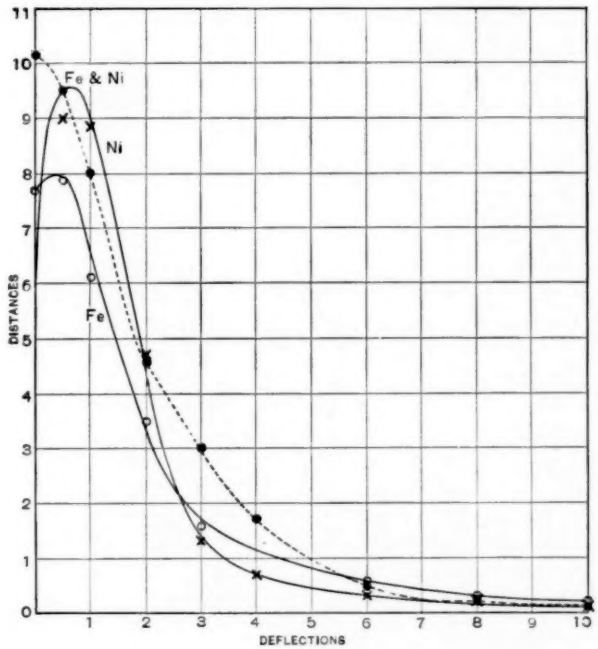


Fig. 2.

The sensitiveness of the detector with a nickel core was not very different from the sensitiveness when an iron core was used. Contrary to expectations, however, the sensitiveness with the nickel core appeared to be the greater in strong fields and with the iron core in weak fields. Both showed a maximum of sensitiveness at a short distance from the magnet, the maximum for nickel being the farther removed. The nickel core proved to be more sensitive than the iron core for distances up to 2.5 cm.

When the detector was worked with the mixed core of iron and nickel wires the deflections of the galvanometer increased as the magnet approached the core, even up to the point of contact. The

curve (Fe and Ni, Fig. 2) lies above the Fe curve at all points and above the Ni curve at most points, showing that a mixed core consisting of annealed piano wire and hard drawn nickel wire, produced a more sensitive detector than was obtained by using a core of piano wire only.

The detector, gave small deflections of the galvanometer when I used an antimony core; also when I used a core of iron filings contained in a thin walled glass tube. In both cases deflections were obtained only when the magnet was near the core. A core of bismuth gave no deflection.

It is probable that the form of the curve of Figs. 1 and 2 depends upon other points than those considered in this paper, as for instance, the frequency and intensity of the oscillations sent out by the transmitter, and the annealing of the steel wires used in the core.

Since electric oscillations appear to "have the power of reducing the effects of magnetic hysteresis," it has occurred to the writer to test their effect upon the hysteresis loss of transformers, armatures, etc. Some experimental work on this subject has been done but I am not yet ready to announce results.

PHYSICS LABORATORY,
INDIANA UNIVERSITY, April, 1903.

STUDIES IN LUMINESCENCE.

By Edward L. Nichols and Ernest Merritt.

I. The Phosphorescence and Fluorescence of Organic Substances at Low Temperatures.

THE experiments here described are preliminary to a more extended study of phosphorescence and fluorescence at low temperatures, which will be, as far as possible, quantitative in character. Before undertaking quantitative experiments it seemed advisable, however, to test a large number of substances qualitatively, so as to determine which are best suited for further study.

The substances thus far tested are chiefly organic compounds of definite composition. Substances like white of egg, milk, ivory, etc., while in many cases possessing bright phosphorescence, seem too indefinite in their composition to be suited for exact work. Among the substances tested are several mentioned by Dewar;[1] but the behavior of the great majority of the substances included in the following tables has not to our knowledge been previously recorded.

The method of testing was briefly as follows: The substance was placed in a glass or porcelain dish in a dark room, and covered with liquid air, which was poured directly upon it. It was then illuminated by the light from a spark passing between magnesium terminals. Fluorescence, if at all intense, could be at once detected; while phosphorescence, if present, was observed after the spark had been stopped. By causing the light to pass through glass before reaching the specimen it was easy to determine, roughly, whether the effects were caused by the ultra-violet or the visible rays. Each substance was also tested at ordinary temperatures. In the case of about half of the substances the effect of X-rays was also tried, both at ordinary temperatures and when the substances were cooled by liquid air.

[1] Dewar, Proc. Royal Soc., 55, p. 340; Proc. Chem. Soc., 10, p. 171; Proc. Royal Inst., 14, p. 665.

Previous experiments have shown that, as regards the effect of low temperatures on phosphorescence, bodies may be divided into at least three classes: (1) Substances in which the power to phosphoresce is increased by cooling; in this class are included substances for which phosphorescence is either weak or entirely absent at ordinary temperatures; (2) substances which are phosphorescent at ordinary temperatures, but which have this power diminished or destroyed at low temperatures; (3) bodies whose behavior, as regards phosphorescence, is apparently unaffected by cold.

We have found many examples of the first class and some examples of the third; but among the organic substances studied no example of the second class was found. Balmain's paint and the phosphorescent sulphides are the only substances tested by us which show diminished phosphorescing power when cooled.

Of the substances tested only 35 failed to show either phosphorescence or fluorescence when cooled to the temperature of liquid air. A list of these inactive substances is given in Table I., p. 361. In a few of these a trace of luminescence may have been present; but if so, the luminosity was so faint as to make it quite unlikely that the substances would prove interesting for further study. It should be noted that the frozen gases tested, viz., ammonia, sulphur dioxide, and ethylene, were contained in glass tubes, whose walls may have served to absorb the active rays of the exciting light.

The substances, 63 in number, which showed phosphorescence at low temperatures, but no fluorescence, are included in Table II. In this table are recorded (1) the approximate intensity of phosphorescence at ordinary temperatures as estimated by the eye, the most brilliant phosphorescence being indicated by the number 5, and the least bright by 1; (2) the intensity when illuminated, and observed, while at the temperature of liquid air, according to the same arbitrary scale as before; (3) the duration of phosphorescence: the number "5" in this column means a duration of several minutes, while "1" indicates a duration of one or two seconds; (4) the color of phosphorescence — in case no color is indicated the phosphorescent light was either white or only slightly colored; (5) the behavior of the substance, at the temperature of liquid air, when stimulated by X-rays.

In the great majority of cases the phosphorescence was due to the ultra-violet rays of the spark. This was shown by the fact that the effect of the spark in producing phosphorescence was either entirely or largely suppressed by the interposition of glass.

In considering the results recorded in Table II., one is struck by the fact that only a few of the substances showed luminescence at ordinary temperatures. The method of observation was not sufficiently refined to permit the detection of very faint phosphorescence, especially if of short duration. Observations made with the phosphoroscope would doubtless show that many of the substances here recorded as inactive at ordinary temperatures really possess a certain amount of activity. Yet the fact remains that the change produced by low temperatures in this property of matter is of a very radical nature.

In all cases where phosphorescence was found both at ordinary temperatures and in liquid air it was also observed throughout the whole intermediate range.

In several instances the greatest intensity of phosphorescence appeared to be at a temperature somewhat above that of liquid air. This was true for example in the case of phthalic anhydride, antipyrin, salicylic acid, arsenious oxide, benzoic acid, alcoholic solution of phenanthrene, coumarin, cetyl alcohol, quinine, and anthranol (Table IV.). Since the observations at intermediate temperatures were made during the rather rapid warming of the substance tested, it is, however, possible that the observed increase in brightness was due to the release of energy which had been stored in the substance. A striking instance of this phenomenon has been reported by Dewar in the case of ammonium platino cyanide.

Only ten substances were found which showed fluorescence at the temperature of liquid air without any noticeable phosphorescence. The behavior of these substances is recorded in Table III.

Of the substances tested the twenty that are included in Table IV. showed both phosphorescence and fluorescence at low temperatures. In these substances also the luminescence at ordinary temperatures was usually either slight or entirely lacking.

In the case of many substances the color of the phosphorescent light changed as the phosphorescence died away; in other words

the different colors of the phosphorescent spectrum decayed at different rates. In some instances there could be little doubt that the observed luminescence was the resultant of two superposed effects, whose rates of decay differed widely. The color of the phosphorescent light was sometimes modified also by temperature, and in some cases by a change in the exciting rays. Some of the most striking cases of color change are mentioned below.

β Acet-naphthalid. — The initially yellow phosphorescence at — 186° C. changes to white as the phosphorescence dies out. The yellow tone is also lacking when the exciting light had passed through glass, while the white phosphorescence remains.

Anisic Acid. — The bright blue phosphorescence seen at low temperatures changes to a greenish yellow as the phosphorescence dies out. At higher temperatures no blue is seen in the phosphorescence, and at the same time the blue fluorescence seen at — 186° disappears.

Benzoic Acid. — The blue fluorescence seen at — 186° C. changes to greenish yellow at somewhat higher temperatures. The maximum phosphorescence seems to occur at a temperature somewhat above that of liquid air. The phosphorescence is initially bright green, losing this color as it dies out.

Calcium Benzoate. — The phosphorescence is at first bright blue, changing rapidly to white as it dies out. The blue fluorescence observed at — 186° C. ceases at slightly higher temperatures, and at the same time the phosphorescence loses its initial blue color.

Meta-carbol. — The phosphorescence at — 186° is initially a brilliant robin's egg blue. But the color is quickly lost as the phosphorescence decays, leaving behind a relatively weak but persistent white.

Metol-Hauff. — Initially blue. At the end of about two seconds the blue changes to green, which persists much longer.

Myricil Alcohol. — At — 186° C. the phosphorescence is a brilliant blue. At higher temperatures the blue changes to a fainter white, which is noticeable through a considerable temperature range.

Palmitic Acid. — Bright green, changing as the phosphorescence dies out to a persistent white.

Piperine. — Bright greenish phosphorescence. When the exciting light is passed through glass the greenish tint is no longer seen.

Phenanthrene (*Alcoholic Solution*). — Bright green phosphorescence of long duration, but changing to white as it dies out. The green part of the phosphorescence is suppressed when the exciting light passes through glass.

Pyrocatechin. — Brilliant green quickly changing to bluish white.

Tetra-chlor Phthalic Acid. — The fluorescence at — 186 ° C. is a bright robins' egg blue. At higher temperatures it changes to yellow.

In the case of the phosphorescent sulphides previous observers [1] have found that phosphorescence excited at ordinary temperatures is suppressed by sudden cooling. With substances of this class the phosphorescence produced by illumination at low temperatures is also small. Observations with benzoic acid indicate that the behavior of that substance is more complicated. Upon exciting phosphorescence at ordinary temperatures and then suddenly cooling in liquid air the phosphorescence is suppressed. The same is true if the substance is excited at some intermediate temperature and afterward cooled. Yet in the case of benzoic acid — contrary to the case of the sulphides — the phosphorescence *excited*, and *observed*, at low temperature is far more brilliant than at ordinary temperatures.

In several instances the luminescence of a solution was compared with that of a solid substance. Although the number of such cases is not sufficient to permit a general conclusion to be drawn, the tests show that important changes in the character of the luminescence are not unusual. Solid anthraquinone, for example, showed a brilliant yellow phosphorescence of short duration; while the frozen alcoholic solution [2] gave a bright bluish phosphorescence of long duration. The behavior of the solution resembled that of the solvent, but when the phosphorescence was compared with that of alcohol the latter was seen to be much weaker.

Phenanthrene offers another good illustration of the effect of

[1] See Pictet, C. R., 119, p. 527; also Lumière, C. R., 128, p. 549, and Trowbridge, *Science*, 10, p. 244.

[2] Commercial methyl alcohol was used as a solvent.

solution. The solid showed blue fluorescence and yellow phosphorescence, both rather bright. When dissolved in absolute alcohol the fluorescence was no longer observed, while the phosphorescence was green instead of yellow, and of much longer duration. In the case of the solution the brightness was also much greater at a temperature somewhat above that of liquid air.

An aqueous solution of piperidene behaved in the same way as the solid salt.

The influence of different solvents in modifying the luminescence phenomena at low temperatures was well brought out in the case of fluorescein. The brilliant fluorescence exhibited by this substance at ordinary temperatures also makes its behavior at low temperatures of especial interest. While solid fluorescein showed no luminescence, either when cold or at room temperature, the alkaline aqueous solution gave the usual brilliant fluorescence until cooled to the freezing point, when all trace of fluorescence disappeared. The temperature at which this sudden change occurred was measured by means of the resistance of a copper wire, and was found to be a few tenths of a degree below the freezing point of the solution. As a check upon this measurement the frozen solution was removed from its test tube for convenience in observation and slowly warmed in the air. Fluorescence was found to begin while the ice was still firm and before any indication of melting could be observed.

The behavior of fluorescein when used as an indicator in volumetric analyses has been explained upon the assumption that it fluoresces only when dissociated. When dissociation is prevented by making the solution acid, or by other means, fluorescence has been found to cease. Since dissociation can scarcely persist in the frozen aqueous solution we should therefore expect fluorescence to cease as soon as the solution solidifies. The apparently contradictory behavior mentioned above seems to result from the presence on the ice of minute drops of liquid which do not freeze until a temperature has been reached slightly below that at which the solution as a whole becomes solid. The change in concentration during the process of freezing naturally lowers the freezing point of those portions of the liquid which are last frozen.

In order to test this point the following experiment was tried.

The solution was introduced into a thick-walled glass tube of small bore, and after being sealed off at one end was connected with a Cailletet pump. The solution was then frozen by the application of cold brine. While still surrounded by the brine and at a temperature a little below the melting point, so that no fluorescence could be seen, pressures of nearly 200 atmospheres were applied by means of the pump. The frozen solution became fluorescent, and became inactive again when the pressure was released. The slight melting caused by pressure, without rise of temperature, restored to the solution its power to fluoresce. The sudden loss of this power is therefore not a temperature change, but is determined by the change of state from a liquid to a solid.

The behavior of fluorescein in alcohol solution is entirely different. A solution in absolute alcohol, rendered alkaline by the addition of dry caustic soda, showed a fluorescence only a little less intense than that of an aqueous solution. When this solution was cooled its fluorescence persisted and even at the temperature of liquid air was only slightly diminished. The frozen solution had the brittle vitreous character usually exhibited by solid alcohol. If the lumi-

TABLE I.

Substances showing neither Phosphorescence nor Fluorescence at — 186° C.

These substances are also inactive at ordinary temperatures.

Acetic acid, copper salt of.
Aceto-nitrile.
Aceto acetic ether, copper salt of.
Ammonia (liquefied gas in glass tube).
Amido-azo-benzol.[1]
Azo benzene.[1]
Alizarin.[1]
Arsenic, As_2O_3 (faintly fluorescent at — 186° with X-rays).
Arsenic sulphide, As_2S_3.[1]
Didymium (aqueous solution).
Ethylene (liquefied gas in glass tube).
Formic acid, copper salt of.
Di-nitro-phenol.
Eosin, sodium salt of (solid).
Fluorescein (solid).
Gold chloride (solution).
Gutta percha.
Indigo.[1]
Iodol.
Magnesium oxide.
Mercuric-cyanide.
Nickel sulphate.
Phenanthraquinone.[1]
Phenyl iodide.
Phenyl mustard.
Pinine (lævo).
Pinine (dextro).
Prussian blue.
Quinone.[1]
Selenium (amorphous).
Sulphur dioxide (liquefied gas in glass tube).
Sulphuric ether.
Thorium oxide (white).
Tri-phenyl-guanadine.
Vanillin.

[1] Also tested with Röntgen Rays and found inactive.

TABLE II.

Substances which show Phosphorescence at —186°, but no Fluorescence.

	18° C.	Behavior at —186° C.			
	Intensity.	Intensity.	Duration.	Color.	X-rays.
Acetamide,	0	1		blue	0
Acetic acid,	0	2	4	blue green	
Acetophenone,	0	3	4	greenish	Ph(3)
Albumin (egg),	0	3		greenish-yellow	
Albumin (blood),	0	1			
Alcohol (absolute),	0	2	2		
Amyl acetate,	0	3	1		
Anthraquinone,	0	4	1	yellow	0
Anthraquinone, alcoholic solution,	0	4	4	bluish-white	
Antipyrine,	0	2	3		Ph(2)
Arsenic: As_2O_3,	0	1	1		0
Arsenic: As_2 '$_3$, vitreous,	0	2			0
Arsenic: As_2S_3,	0	trace			0
Asparagin,	1	3	3	bluish	0
Benzaldehyde,	0	1	4		Ph(1)
Benzophenone,	0	3	2		Ph(2)
Camphor,	0	1			0
Carbostyril,	0	3	2		0
Casein,	0	1		bluish	
Cetyl alcohol,	0	5	4	bluish	
Citric acid,	1	3	3	greenish	
Coumarin,	0	1	2		
Diogen,	0	1	1		
Erythrite,	0	3	2		
Eucalyptol,	0	faint			0
Fusel oil,	0	3	3		
Glucose,	0	2	3		
Hydrogen peroxide,	0	2	3		
Hydro-azo-benzene,	0	1	2	greenish	0
Hydroquinone,	0	3	3	greenish	
Limonene (dextro),	0	1	1		
Malachite green (leuko compound),	0	3	3	greenish	
Menthol,	fl(trace)	3	3		0
Meta carbol,	2	5	3	green	
Methyl-amine hydrochloride,	0	3	3		0
Metol-Hauff,	0	4	1	blue	
Myricil alcohol,	fl(trace)	5	3	blue	
Napthalene,	0	1			Fl(1)
Palmitic acid,	0	4	3	green	

TABLE II.—*Continued.*

Substances which show Phosphorescence at —186°, but no Fluorescence.

	18° C.	Behavior at —186° C.			
	Intensity.	Intensity.	Duration.	Color.	X-rays.
Phenanthrene [1] (alcoholic solution),	0	5	4	green	
Phenolphthalein (alkaline aqueous solution),	0	3	3		0
Phenolphthalein, alcoholic solution,	0	3	3	blue	
Phenyl acetic acid,	0	5	3	white	Ph(3)
Phenyl propiolic acid,	fl. (trace)	1			
Phenyl-thio-carbamide,	0	1	2		
Phenyl-thio-methane,	0	1	2		0
Phthalic acid,	2 yellowish	3	2	greenish yellow	Ph(3)
Phthalic anhydride,	2 greenish	3	2	greenish	Ph(1)
Phthalic acid (iso-),	1 bluish	4	3	blue	0
Phthalic acid (tere-),	0	5	4	blue	0
Phosphorous pentoxide,	1	3	3		
Piperidene,	0	5	3	greenish	0
Pyradine,	0	1			
Pyrocatechin,	1	5	4	green	
Quinine (alkaloid),	0	3	2		0
Quinine sulphate (solid),	0	3	2		0
Quinoline,	0	2	3		0
Salicylic acid,	fl. (trace)	1	3		Ph(1)
Thio-carb-analide,	0	1			
Thiophene,	0	3	2		0
Theo-urea,	0	faint			0
Tolidol (Pfabe),	0	4	3	bluish	

[1] For solid phenanthrene see Table IV.

TABLE III.

Substances Showing Fluorescence at Low Temperatures, but no Phosphorescence.

	18° C.	Behavior at —186° C.		
	Intensity.	Intensity.	Color.	X-rays.
Acridene.	0	4	green	
Carbazol.	2	3	blue-violet	0
Cyanin (alcoholic solution).	0	4	red	
Eikonogen.	0	3	purple	fluorescence (1)
Fuchsin (alcholic solution).	0	3	red	
Napthoic acid.	3	5	blue	
Piperine.	0	5	blue	
Uranium Nitrate.	Fluorescence not decreased by cold.			
Uranyl fluorid-fluor-ammonium.	4	4	green	
Uranium oxide (yellow).	0	3	greenish	

TABLE IV.

Substances showing both Phosphorescence and Fluorescence at — 186° C.

		18° C.	Behavior at —186° C.		
		Intensity.	Intensity.	Duration.	Color.
β-Acet-napthalide.	Ph	0	3	3	yellow
	Fl	2	3		purple
	x	—	—	—	
Aceto acetic ether.	Ph	0	3	3	white
	Fl	0	1	—	bluish
	x	0	0		
Acridine sulphate (solution).	Ph	0	1	2	
	Fl	0	1		
	x	—	—	—	
Anisic acid.	Ph	1	5	2	blue
	Fl	1	3		blue
	x	—	—		
Anthracene.	Ph	0	1	3	white
	Fl	4	4		blue
	x	trace	trace		
Anthranol.	Ph	0	3	1	yellow
	Fl	0	4		lemon yellow
	x				
Benzoic acid.	Ph	1	3	3	green
	Fl	0	3		blue
	x	fl. (trace)	phos. (4)	4	
Calcium benzoate.	Ph	1	3	3	blue
	Fl	0	3		blue
	x	trace	phos. (3)		white
Dianthracene.	Ph	0	3	2	yellow
	Fl	2	4		blue
	x	—	—	—	
Dimethyl dianthracene.	Ph	0	1	3	
	Fl	trace (?)	2		greenish
	x	—	—	—	
Diphenyl methane.	Ph	0	5	4	greenish yellow
	Fl	3	3		purple
	x	0	0		
Ethyl carbamate.	Ph	0	4	3	
	Fl	0	2		
	x	0	0		
Imogen.	Ph	0	1		
	Fl	trace (?)	4		violet
	x	—	—	—	

TABLE IV.—*Continued.*

Substances showing both Phosphorescence and Fluorescence at — 186° *C.*

		18° C.	Behavior at—186° C.		
		Intensity.	Intensity.	Duration.	Color.
Mellite.	Ph	2	3	1	purple
	Fl	2	4		purple
	x	0	faint		
Mellitic acid.	Ph	trace	5	3	bluish
	Fl	0	3		blue
	x	—	—	—	
Methyl salycilate.	Ph	0	1	2	
	Fl	0	4		blue
	x	0	trace		
Oxalic acid.	Ph	0	1	2	white
	Fl	0	2		violet
	x	—	—		
Phenanthrene.	Ph	0	4	2	yellow
	Fl	2	4		blue
	x	2	3		
Quinine sulphate (aqueous solution).	Ph	0	3		
	Fl	4	4		blue
	x	—	—		
Stearic acid.	Ph	0	5	1	green
	Fl	1	0		
	x	—	—		
Tetra-chlor phthalic acid.	Ph	0	3	2	
	Fl	0	4		blue
	x	0	5 (Fl.)		white
Tri-phenyl methane.	Ph	0	3	4	white
	Fl	2	2		blue
	x	0	0		

nescence of fluorescein is due to its dissociation we are thus forced to conclude that dissociation is still possible in solid alcohol at a temperature of — 186° C.

Instances are not lacking where substances that are closely related chemically behave in a similar manner as regards their luminescence at low temperatures. Benzoic acid and calcium benzoate offer a good illustration. The various members of the phthalic acid group also show a general similarity in their behavior. But attempts to trace a general relation between luminescence and chemical structure have not been successful.

SOME FURTHER OBSERVATIONS ON THE RADIATION PRODUCED IN AN ALTERNATING CONDENSER FIELD.

BY FERNANDO SANFORD.

IN an article published in the PHYSICAL REVIEW of December, 1903, Vol. XVII., p. 441, the present writer described some experiments which had been made on a form of radiation which is given off from the kathode of an air condenser connected to the terminals of an induction coil. It was shown that this radiation is capable of refraction, total reflection and polarization, but when the article was written its wave-length had not been measured. Since that time I have succeeded in measuring the wave-length of the radiation from several metals and have made some observations which enable me to explain some of the phenomena which were not before understood and to correct an erroneous conclusion as to the two kinds of radiation which were supposed to be sent off from metal plates placed in the field of the condenser.

The wave-length measurements were made by means of a Wallace celluloid replica of a Rowland plane grating having 14,438 lines to one inch. This grating was found to be fairly transparent to the radiation and to give definite spectra of the first order. The grating was placed over a slit about 3 mm. wide cut in a hard rubber screen which was placed between the source of the radiation and a photographic plate. The distance of the grating from the sensitive plate was, in the various experiments, from 4 cm. to 5 cm. This distance gave a displacement of the first diffracted image of the slit of from 8 mm. to more than 1 cm. The bands were generally sharply defined in the photographs, indicating that the radiation was virtually all of one wave-length from a given metal, and their displacement could be measured to within two or three tenths of a millimeter. The distance between the grating and the sensitive plate could be measured with a still higher percentage of accuracy,

so that the error of measurement of the wave-length ought not to exceed four per cent. As a matter of fact, four different measurements of the wave-length from copper were made at different times using different copper strips as radiators and with different distances between the grating and the plate with a maximum difference in the four measurements of only 1 per cent. This close agreement must be regarded as accidental, but it is believed that the measurements are in general accurate to within four per cent.

The wave-lengths so far determined are as follows: For the radiation from aluminum and from silver, $\lambda = 350\,\mu\mu$. For the radiation from copper $\lambda = 372\,\mu\mu$ and for the zinc radiation $\lambda = 377\,\mu\mu$. As predicted in the preceding paper, this radiation is in the ultra-violet part of the spectrum and only a short distance beyond the visible spectrum.

No difference was found in the wave-length of the radiation from a piece of sheet copper when it was connected to the kathode of the induction coil and when it was insulated between the plates of a tinfoil condenser and gave off the radiation by induction. This observation contradicts one of the conclusions of the former paper concerning two kinds of radiation from a metal plate when insulated in the condenser field. The preceding paper mentioned the fact that when a strip of sheet metal was used as the radiator and an opaque screen with a slit was placed between the radiator and the sensitive plate two images of the slit were regularly formed on the plate, and that when a prism was placed across a part of the slit these two images were sometimes differently refracted. In the experiments where the radiating plate was connected directly to the kathode but one image of the slit was produced, and reasons were given for believing that these two images were produced by reflected and induced radiation. A further attempt to trace the origin of the two images has shown that they were due to the radiation from the two opposite edges of the metal strip. Even the earliest experiments in coin photography showed that the intensity of the radiation from the edges and convex surfaces of the coins was greater than from the plane faces, and this fact was mentioned in the paper on "Some Experiments in Electric Photography" in the PHYSICAL REVIEW, Vol. II., p. 60, but this difference was not

thought to be great enough to account for the phenomenon of the double image, though it was several times suspected to be the cause. The experiments with the radiator connected to the kathode seemed to exclude this explanation, but in those experiments a larger radiator was used and it was arranged so that only the radiation from the central part of the plate could reach the sensitive plate through the slit.

Later experiments have shown that when a thin piece of sheet metal is used as a radiator nearly all the radiation is from its edges. This radiation is diffuse, and apparently goes off in one direction nearly or quite as well as in another. Accordingly when a narrow strip of sheet metal was used as a radiator, as described on page 451 of the former paper, each edge served as a line source of radiation and two images of the slit were produced. Since the radiation from the two sources passed through the prism at different angles of incidence their deviation by the prism was different, and accordingly there seemed to be two kinds of radiation having different refractive indices. Many experiments have since been made with radiators of various width, both connected to the kathode and insulated in the condenser field, and there can be no doubt of this being the true explanation of the two images of the slit. In the latest experiments the radiating plate has been placed horizontal between the two horizontal condenser plates with one edge in front of and parallel to a horizontal slit in the opaque screen. With this arrangement only one image of the slit is produced and a narrower slit can be used than in the former experiments.

The sharp lines of separation between the radiations from the two radiating surfaces when separated by the glass prism as shown in the photographs on pp. 446 and 447 of the former paper are also explained by this phenomenon. When feeble radiators, as wood, paper, mica and glass are used, the principal source of radiation which reached the photographic plate was the edge of the radiating strip nearest the prism. The other edge of the strip was so far away that its effect upon the central part of the photographic plate was inappreciable in the photograph. When a metal plate was used as a radiator the radiation from its farther edge was still strong enough to be appreciable on the part of the plate which

also received the radiation from the wood or paper on the other side.

The same phenomenon likewise explains the fact that when a window was cut in the top of the box camera and covered with the metal kathode the intensity of the radiation upon the sensitive plate beneath was not sensibly greater than when the whole box was covered by the *papier maché* slide. This was due to the fact that but little radiation was sent off from the central part of the kathode plate which was placed over the window.

To sum up the observations to the present time, it may be said that when the terminals of an induction coil are connected to the plates of an air condenser and the current is interrupted in the primary coil the kathode plate gives off a radiation which possesses many, if not all, the properties of ordinary ultra-violet light. The wave-length of this radiation differs when the kathode plate is made of different metals, and for the metals aluminum, silver, copper and zinc it lies between 350 $\mu\mu$ and 380 $\mu\mu$. If a plate of metal or other substance be placed between the condenser plates it gives off the same radiation as when joined by conducting wires to the kathode, but with less intensity. In the case of a copper plate between tinfoil condenser plates this induced radiation has the same wave-length as when the copper plate is made the kathode of the condenser. Every body which has yet been tried may serve as a source of this induced radiation.

STANFORD UNIVERSITY,
February 6, 1904.

PROCEEDINGS

OF THE

AMERICAN PHYSICAL SOCIETY.

THE HALL EFFECT IN THE ELECTRIC ARC.[1]

BY C. D. CHILD.

IF two carbon pencils are so placed in an arc that there is little or no potential difference between them, a potential difference is produced by creating a magnetic field about the arc. This may be as high as 1.5 volts. It appears to be similar to the Hall effect in metals, and if it is this effect, it would show that the negative ions have a velocity enormously greater than that of the positive.

The effect can not be produced by blowing the arc to one side, nor by moving the carbon pencils to one side of the arc. Rapidly reversing the field and with each reversal reversing the connections to the voltmeter does not diminish the effect.

The effect decreases with decreasing strength of the field. Changes in the current through the arc and in the length of the arc do not appreciably influence it.

Putting salts in the arc diminishes the drop of potential at the anode and it also diminishes the effect here studied. With KNO_3 the anode drop becomes as small as the cathode and with it the potential difference between the two pencils becomes approximately zero.

However, in a vacuum where the pressure is approximately 1 cm. of mercury the effect also disappears and here the ratio between the drop at the anode and that at the cathode is nearly the same as in air at normal pressure. With an enclosed arc the effect is the same as in air. Diminishing the pressure of air produced no great change in the observed potential difference until a pressure of 20 cm. was reached. Between that and 10 cm. the effect was greatly diminished, and between 10 cm. and 1 cm., as far as could be observed, it entirely disappeared. Though the ratio between the anode and the cathode drop is not greatly

[1] Abstract of a paper presented at a meeting of the Physical Society held on February 27, 1904.

changed, they each separately decrease, the principle change being between pressures of 20 cm. and 1 cm.

The effect, therefore, is not diminished by any change in the ratio between the anode and cathode drop in potential, but as far as has now been observed it decreases when the voltage between the terminals of the arc decreases, becoming inappreciable when this becomes less than about 30 volts.

No definite explanation can at present be given of the observed phenomena.

NEW BOOKS.

Thermodynamik. Sammlung Schubert, xxxix. By Dr. W. VOIGT, Professor der theoretischen Physik an der Universität Göttingen. I. Band. Einleitung: Thermometrie, Kalorimetrie, Wärmeleitung. — Erster Teil: Thermisch-mechanische Umsetzungen. Mit 43 Figuren. 13 x 19 cm.; pp. xv + 360. Leipzig, G. J. Göschensche Verlagshandlung, 1903. Price, cloth, 10 marks.

It is not improbable that the best way to present the subject of thermodynamics is to give an account of its history — to show how, step by step, difficulties arose and were overcome, until the present beautiful body of theory was attained. Yet there is much to be said in favor of a more deductive treatment. On this plan, the first and second laws of thermodynamics may be established by inductive reasoning, the criteria of equilibrium and of stability be obtained through formulation of the spontaneous dissipation of work-availability, and from this basis the differential theory of the subject be developed in an orderly manner, and illustrated by such approximate integral theory as is at present possible. This is an interesting and instructive method, and it has the advantage of introducing the absolute temperature without any appeal to the properties of those overworked hypothetical substances, the ideal gases.

In the present work, Voigt has followed neither the one nor the other of these two plans. In his treatment the influence of the historical method is noticeable, for the theory of the subject is approached through the properties of ideal gases. The text of the present first volume is arranged in four chapters and an introduction. The introduction discusses thermometry, calorimetry, and heat-conduction. In the first chapter, an outline of the elements of the mechanics of a particle and of a system of particles is made to lead up to recognition of the equivalence of work and heat. The second chapter works up the thermodynamics of ideal gases. In the third chapter the second law is developed for bodies whose states of thermodynamic equilibrium are determined by two independent variables; and in the fourth the principles of thermodynamics are applied to systems whose states are determined by any number of variables. This concludes the volume and the first part of the work. Subsequent parts are to deal with chemical processes and changes of state of aggregation, electromagnetic actions, and applications of the principles of thermodynamics to radiation phenomena.

It is thus apparent that the treatment is given a wide scope. This is doubtless the excuse for the inclusion in the introduction of thirty pages on the theory of the conduction of heat. Some of the space so taken might better have been occupied by a clear explanation of how it is that the laws of Boyle and Gay-Lussac lead to the scale of temperatures of the ideal-gas thermometer. The brief statement in the text is not clear. The laws in question are not even stated separately. In the section on calorimetry the idea of a quantity of heat is introduced by means of the caloric fluid hypothesis. This *interpretation* of a certain class of facts is well enough as a matter of history, yet in this age of the world it should be emphatically pointed out that by a "quantity of heat" is *meant* the work value of a definite kind of change of the state of a body. It is to be noted at this point that Voigt employs Carl Neumann's hook-shaped d to indicate an inexact differential expression. This is, of course, a matter of no moment; yet the reviewer is grieved to see Voigt's own admirable notation $d'Q$ abandoned in favor of Neumann's impracticable idea. Apart from these details, Voigt's discussion of thermometry and calorimetry can only be commended.

In Chapter I., "The Equation of Energy and the Mechanical Equivalent of Heat," the mechanical principle of the conservation of energy is derived. Then, from the experimentally established equivalence of work and heat, it is concluded that additions of work and heat to a body "increase the work-availability, the energy, of the body," and the first law of thermodynamics is written down. The relation of this law to the impossibility of a "perpetual motion of the first kind" is discussed, a half dozen methods of determining the mechanical equivalent are described, and the law is applied to the heat-development of a falling meteor and to the Mayer and Helmholtz theories of solar-heat. It is not made clear that the "mechanical equivalent" is the specific heat of water.

We now come, in Chapter II., to the thermodynamics of ideal gases. Here preference is throughout given to volume and pressure as independent variables. By the "absolute teperature" θ is meant the temperature-reading of the ideal-gas thermometer. Reversible changes of the state of a homogeneous body under uniform pressure, in particular reversible isometric, isobaric, isothermal, adiabatic, and isodynamic paths, are described. The existence of a family of reversible adiabatic paths is gotten at by writing the heat equation in the form

$$d'\Omega = \Omega_1 dV + \Omega_2 dp = 0,$$

which, being always integrable, leads to a relation

$$f(V, p) = H,$$

where H is the parameter of the family of adiabatics. Hereupon we find

$$d'\Omega = \varphi(H, \theta)dH + \varphi'(H, \theta)d\theta,$$

or, since $d'\Omega$ varnishes for constant H,

$$d'\Omega = \varphi(H, \theta)dH,$$

a result that is not calculated to help the beginner much. Now the existence of ideal gases is assumed, and it is shown that, for the differential of the energy of the mass M,

$$dE = M\gamma_v d\theta.$$

The argument is clumsy, because of the selection of V, p as state-variables. Then, by an untransparent calculation that to a beginner could seem only a juggling with equations, we finally find, after one hundred and twenty-two pages,

$$d'\Omega = \theta dH.$$

Next, the form of $H = f(V, p)$ is found; it is shown that over a reversible cycle $\int(d'\Omega/\theta) = 0$; and H is termed the entropy of the ideal gas. The remainder of the chapter is concerned with the ratio γ_p/γ_v of the specific heats, an extensive geometrical and physical study of curves of the form $V^\kappa p = f$, a detailed examination of various reversible cycles with ideal gases, and applications to convective equilibrium in the earth's atmosphere and in a gravitating gaseous sphere.

After nearly two hundred pages of text, Chapter III. takes up the general examination of the thermodynamics of bodies whose states are determined by two variables. From the fundamental principles of Clausius and of Thomson it is concluded that the efficiency of a Carnot cycle is independent of the working system, and the formulation $d'\Omega = \theta dH$ is established. No reference is made to the clarifying principle that only processes that will spontaneously occur can be utilized as compensation for the doing of work. The laws of thermodynamics are now applied to yield Maxwell's "thermodynamic relations" in p,v, v,θ, p,θ, and θ,η. The relations in v,η and p,η are omitted. Further formulations obtained are those for the specific heats and for the heat-differential, in the same pairs of variables. A short sketch of the properties of the "first and second thermodynamic potentials" (the free energy and the thermodynamic potential) is added.

A section on liquids and solids gives certain special applications of the thermodynamic equations to these states. On the whole the treatment is good, yet one is surprised to find that in the energy equation in volume and temperature,

$$de = \gamma_v d\theta - \left(p - \theta\frac{\partial p}{\partial \theta}\right)dv,$$

the term in dv is asserted to represent an absorption of work unaccompanied by transfer of heat. Surely this is nonsense. It seems to have been assumed that $\gamma_v d\theta$ is the total absorption of heat.

The heading of a section on "actual" gases is disturbing, since we have been so confidently assured of the existence of gases ideal "*in voller Strenge.*" The section gives a good treatment of the porous-plug experiment, and of the theory of Linde's refrigerating machine. Up to this point (for 240 pages) the temperature has appeared in all formulas as the temperature $\theta = pv/B$ of the ideal-gas thermometer. Apparently the appearance of "actual" gases is making trouble, for now Thomson's scale of absolute temperatures is taken up. The scale is defined, and it is shown how the results of work with the porous-plug may be utilized for the correction of the scale of a gas-thermometer. A section on the increase of the entropy of an isolated two-variable system during spontaneous change, and one on the thermodynamic behavior of a stressed cylindrical solid, complete the chapter.

The closing chapter, on the thermodynamics of bodies whose states are determined by any number of variables, need not be discussed; since the character and plan of the book should be sufficiently gauged from what has already been said. It seems to the reviewer that here, as elsewhere, the treatment is characterized rather by command of detail than by breadth of view.

The work appears in the *Sammlung Schubert*, a series of text-books on various topics of pure and applied mathematics. The mechanical execution is not what it should be, none of the books of this series are very easy to read. The proofreading, however, has been well done; and the author has done what he could to relieve the eye, by breaking the text into short articles with topical headings. This is a distinct help. Very few references to the original literature are given. The volume is dedicated to Lord Kelvin. J. E. TREVOR.

Elementary Applied Mechanics. By ALEXANDER & THOMSON. The Macmillan Co., New York, 1902.

Starting with a brief presentation of the subject of lineal stress and strain the first chapter of this book includes also a discussion of elasticity and resilience. These subjects are very clearly presented and thoroughly prepare the reader to understand these terms as used in the analytical discussions which follow in the body of the book. Chapter 2 treats of internal stress and strain, simple and compound. Chapter 3 is devoted to Rankine's method of the ellipse of stress, giving the direct and inverse problems and illustrating them by photographs of a moving model. Next follow Chapters 4 and 5 treating the practical application of the foregoing discussions to the stability of earth work and the scientific

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design of masonry retaining walls. These first 5 chapters form as it were the first division of the book.

It should be noted here that the authors make and maintain a careful distinction between the terms strain and stress, the first invariably denoting distance, the latter force. The term strain always means the stretch due to a tensile stress or the shrinkage due to a compressive stress. The use of these terms in this way is rigidly adhered to throughout and leaves no lingering doubt in the mind of the reader as to the appropriateness of such a distinction.

Beginning with transverse stress in Chapter 6 the next eight chapters to Chapter 14 inclusive are taken up with a discussion of the different methods of loading beams and girders, and of the resulting bending moments and shearing stresses, including a discussion of the continuous girder. Next follows the subject of resistance to bending and shearing with the introduction of moments of inertia of the usual shapes, the treatment being both analytical and graphical and very completely illustrated by practical examples. In Chapter 19 there is a short presentation of the subject of torsion, and combined bending and torsion, followed by the subheading: "Thrust and Induced Bending," under which heading the Rankine-Gordon formula for columns is analytically deduced. The treatment of this subject of column formulæ, to which most modern writers have devoted much space, is here very brief, being confined to the rational and empirical development of the Rankine-Gordon formula, all others being brushed aside in the following language: "This formula for many years was thought to be too general and in America most eminent engineers made formulæ of their own of like form but varied to suit different cross sections, in a way that led to great confusion. Fidler in the most skilful way arranged the Rankine-Gordon formula in tabulated results which agree with great exactness with the results of more recent exhaustive and elaborate experiments made on struts with the skeleton sections. His tabulated results agree also with the results of the special formulæ for special section."

The authors' criticism of Euler's formula is also worth noting: "In our opinion Euler's formula is quite unsuited for struts for heavy engineering steel work. Euler contemplates a load which will *just not bend* the strut. Now the whole duty of a steel strut in a structure is to resist bending and bend it will no matter how it is designed, for it will take a *set* to one side or other with its own weight if with nothing else; for the weight of the immense struts in modern structures is very considerable. Also heat will distort a strut; and in riveted work the straining of the adjacent members sends bending strains along a strut, which must be designed with an ample radius of gyration, and it is undesirable to talk about a load which will *just not bend* it."

Chapter 20, treating of the steel arched girder or the braced arch, as Americans usually term it, is in the writer's opinion, the most unsatisfactory chapter in the book. The subject is thoroughly discussed in a general way and under all conditions, but there is no analytical treatment of the particular cases, and it is almost inconceivable that a beginner, having read the book conscientiously up to this point should be able to understand from the graphical presentation here given, how to take out the stresses in a braced arch. "For bridges," say the authors, "the steel arched girder seems likely to entirely supersede the suspension bridge." This statement may be true to some extent with English engineers, but American Engineers as a rule are governed in the selection of the braced arch or the suspension bridge by the local conditions and problems which affect the cost and which have to be solved for each case specially and separately. Such a statement as that quoted, therefore, seems wide of the mark.

In Chapter 21, on the other hand, there is a very simple and complete discussion of the analysis of triangular trussing of girders with horizontal chords. The authors claim to have followed the demonstrations of Lévy on this subject, but they have gone further in some instances and the writer has seen no better presentation of this subject in the English language than is here found. The treatment is thoroughly analytical containing rational, not empirical, solutions for the necessary and sufficient weight of a girder. This chapter alone should make the book of great value to the reference library.

The last Chapter, 22, deals with the scientific design of masonry arches and contains graphical as well as analytical solutions of the problems involved, and several tables of practical value. Carefully prepared examples illustrate this part of the work and the pictorial illustrations are particularly instructive and intelligible.

As a whole, this work is much too analytical to become an elementary text book for American students, but possesses great value as a reference work for those wanting a more detailed analysis of some of the subjects than is presented in the ordinary text books. An abstract analysis of the most general case is not as easily comprehended and applied by the beginner as are separate solutions of the most useful particular cases. The graphical demonstrations of many of the problems are somewhat cumbersome and not presented clearly enough for the beginner, but in justice to the authors, it should be said that they disclaim any intention of teaching the subject of graphical statics in this volume. The analytical demonstrations, on the other hand, are for the most part very clear and thorough and their practical application is illustrated by carefully prepared examples.

All of the subject matter of the book has been arranged with careful

attention to a rational development, the different theorems and demonstrations being built up step by step consecutively from preceding matter. A discussion of the practical value of results arrived at seems to have been secondary to the main object of establishing a complete theoretical development of the elementary subject. There is little or no reference to such practical topics as factors of safety, permissible unit stresses, wind forces, details of construction, or shop practice, etc., etc., which are usually given prominence by modern writers on applied mechanics. It is perhaps as well to separate topics relating to strength and quality of materials from a theoretical work on mechanics, although it is not usually done. All things considered it seems that this volume might have been more appropriately called "Theoretical Applied Mechanics" if not an inconsistent title. W. W. CREHORE.

Astrophysical Problems. By AGNES M. CLERKE. London, A. & C. Black, 1903. Pp. 545.

Miss Clerke's admirable presentation of the past and present of astrophysical knowledge in this book supplies the astrophysicist with a compendium of facts and a body of discussions which will doubtless in many cases serve as the starting points for new discovery. After an introduction, the main divisions are: (1) Problems in Solar Physics, (2) Problems in Sidereal Physics. Fourteen chapters are devoted to minute and particular discussion of the various aspects and problems connected with corona, chromosphere, reversing layer, and photosphere, together with the problems of "the sun's rotation," "the solar cycle," and "the sun as a whole."

In part 2, after an introductory chapter on the progress of sidereal physics, twelve chapters are devoted to the classification of stellar spectra and a discussion of spectral types. The subject of stellar variables is is treated at length in eight chapters, including a chapter on temporary stars. Star clusters are treated in four chapters, and nebulæ in ten. The book closes with a discussion of the physics of the Milky Way. An appendix contains a table of stars with variable spectra, and a list of spectroscopic binaries. The book has been very carefully and fully indexed, and abundant references to the literature appear as footnotes to the text. That the illustrations, which are numerous, are not equal to the text is due to the selection by the publisher of a soft rough-surfaced paper, not well suited to bring out that fineness of detail in the plates which is indispensable in the reproduction of star and spectrum photographs.

The book is more than a compendium or compilation of fact and theory, it is an interpretation of results and a judicial weighing of evidence. Even in parts of the subject where evidence is most chaotic, and the dis-

cussion most involved, the exposition is clear and the main points at issue are rarely lost sight of. The work abounds in suggestion and often indicates specifically the directions in which important new facts should be sought. The clear and vivacious style of the author, in which the utmost possibilities of our language are employed to avoid the sin of vain repetitions, makes the presentation of facts, however dry and wearisome in themselves always lively and interesting reading. To the physicist the book will prove a valuable possession, to the astrophysicist it must needs be indispensable. If equal talent could be induced to do for other collateral branches of physics what Miss Clerke has so successfully done for astrophysics, it would mark a most important achievement.

E. F. NICHOLS.

Elements of Physics. By E. J. ANDREWS and H. N. HOWLAND. New York, The Macmillan Company, 1903. Pp. i–ix, 1–386 and Manual of Experiments, pp. 52.

In the preface the authors state their aims to be: (1) To readjust the limits of the subject, (2) to give clear notions by means of the scientific method, (3) to make prominent the practical bearings of physics, (4) to base the work on a few fundamental principles. In the main we think they have succeeded. The book is carefully written, parts are well arranged, many parts having been expanded more than is usual. Its size impresses one as large for an elementary book. Part of its bulk is accounted for by the Manual of Experiments comprising 52 pages which has been bound with the text. The book is a text-book for high school pupils' use. It concerns itself with explaining physical phenomena. No experiments for the lecture table or for the student are found in the body of the book. As noted already 63 experiments for students comprise 52 pages at the end of the book. Teachers will always differ as to the kind of experiments which should be introduced into a laboratory. In our opinion experiment 1 on Inertia, experiment 2 on Porosity, experiment 3 on Cohesion, experiment 9 on The Effect of Mass on Falling Bodies, experiment 28 on the Production of Heat, experiment 31 on the Conduction of Heat, and experiment 48 on The Motion of Sonorous Bodies, are all more suitable for the lecture table than for the laboratory. The remainder of the experiments, although suitable enough for laboratory use, are as a rule very easy, much easier than those described in the Laboratory Manual of Timmerman, Cheston and Dean to be described later on.

The authors have tried to make an interesting book and have thus emphasized the phenomenal and experimental as contrasted with the mathematical side of the subject. If the book gains somewhat in interest by this it loses that elegance and precision which one feels in some other books, Carhart and Chute for example.

Some devices introduced are to be commended for originality and clearness. This is true of Fig. 130, which represents a water-analogy of Wheatstone's bridge. No attempt has been made to emphasize the importance of the cuts. They are clear enough but inconspicuous and often crude. The two time-worn diagrams on page 166 which represent in cross-section the parts of a steam-engine and which have done service in so many different books, provoke a smile by their appearance here. They both contain a serious mistake which it is surprising has been allowed to go so long uncorrected.

Writers of elementary text-books in physics are liable to go to one or the other of two extremes. They either make the subject dry and uninteresting by making discussions brief and mathematical, or by avoiding mathematics and introducing much discussion of phenomena and experiments expand the subject to great length. This latter method often leads to prolixity as appears at times to be the case with the book before us. We note the expressions "of course" and "in fact" seven times repeated on six consecutive pages and in every case these expressions might be omitted without in any way obscuring the meaning of the text. Words of this character in a text-book are not only superfluous but a positive blemish.

On page 173 "*artificial* ice" is referred to and the process of its manufacture explained. As the manufacturers of this article are themselves very particular to call it *manufactured* and not *artificial*, and this for obvious reasons, it would seem as though writers of text-books ought to follow the example of the manufacturers. The tendency to prolixity becomes in at least one instance "talk." This appears in the paragraph on "Perpetual Motion," page 175. We note one mistake. On page 151 is this definition: "The heat required to raise any substance one degree will be its specific heat." This is really a definition of *thermal capacity*. The definition above should have inserted after *raise* "one gram of," in which case it becomes correct. The book contains numerous problems and exercises which are an important and very useful feature.

R. H. CORNISH.

Entropy. By JAMES SWINBURNE. Westminster, Archibald Constable & Co., London, 1904. Pp. x + 137.

Some time ago, in an address to the Institution of Electrical Engineers, Mr. Swinburne made a remark upon the definition of entropy and its use by engineers which has been the occasion of a spirited discussion in several engineering journals. The remark was to the effect that no English work upon the steam-engine gives a correct definition of this quantity, and that most treatises on physics, English and foreign, also contain incorrect definitions. The present look is an outcome of this disdussion and sets forth in detail the author's position. It must not be

inferred, from the somewhat sweeping statement just quoted, that the book belongs to the class which includes the works of the circle squarers and the anti-Newtonian astronomers. It does not hold that the results of the founders of thermodynamics are wrong, but only that their mode of exposition was unfortunate in that it has led astray many of their followers, including most engineers and text book writers, particularly in the treatment of irreversible processes, that is to say, the only ones which actually occur in practice.

Most of us will be ready to agree with the author as to the errors in many text books, and the desirability of a more careful treatment of irreversible processes. But there is likely to be more difference of opinion in regards to the alternative which he offers. Very radical changes are suggested in definitions, in axioms, and in the interpretation of equations and diagrams; and some of these, at least, are of doubtful utility. Some of the difficulties, which the author finds in the ordinary presentation, have their origin in his unreserved adoption, from the text books which he criticizes, of the concept, "heat of a body," or "quantity of heat in a body"; that this is a fertile source of confusion is not surprising when it is remembered that entropy was introduced by Clausius just because there is no physical reality corresponding to these phrases. Again, the views of the author upon the nature of the entropy-temperature diagram are not likely to meet with universal acceptance. Students of elementary mechanics find difficulty in comprehending the law of action and reaction until they clearly recognize that there are two bodies (or two parts of the same body) concerned, and that the "action" is the force upon one, the "reaction" upon the other. In like manner, the normal difficulties of the study of irreversible thermodynamic processes are greatly exaggerated if one is allowed to forget that, in such a process, there must be two bodies, or at least two parts of the same body in different states with regard to temperature and pressure. Remembering this, it is plain that neither the entropy-temperature nor the volume-pressure diagram is suitable for representing such processes. If parts of a body have different pressures and temperatures, its state cannot be represented upon these diagrams, for no averaging of the "intensities" is permissable; and if a body, homogeneous with respect to temperature and pressure, goes through any process with an outside body, the trace of its series of states upon either of these diagrams can give no indication as to whether the process was performed reversibly or irreversibly. For such purposes, diagrams, in which additive quantities like volume, energy and entropy are the coördinates, are alone suitable; and this was clearly pointed out by Gibbs in the paper in which the entropy-temperature diagram was first described. In plotting the entropy-temperature diagram for the steam-engine, complications of this sort, incident upon wire-drawing,

the exchange of heat with the cylinder walls, etc., together with the indefiniteness in the notion of heat referred to above, lead Mr. Swinburne to the conclusion that areas on this diagram are not quantities of heat unless the processes are reversible. An analogous and parallel conclusion would be that areas on the volume-pressure diagram are not quantities of work unless the engine and shafting are frictionless. It is most necessary that the engineer should recognize that the entropy-temperature diagram, as usually constructed, does not give exactly the work done in the cylinder, just as it is necessary for him to make a distinction between indicated and brake horse-power; but a little care in specifying what entropies, temperatures and works one is dealing with, renders unnecessary, it seems to me, a change in the fundamental interpretation of either diagram.

Although the reader may differ with the author upon many points, he cannot fail to be sensible of the service which has been done in calling attention to difficulties and to errors, actual and potential. Much originality and independence of thought is displayed, and there is no special pleading but a very honest endeavor to clear up difficulties and get at the truth.

H. A. BUMSTEAD.

Electrical Machinery. Vol. I., Electric, Magnetic and Electrostatic Circuits. By HARRIS J. RYAN, HENRY A. NORRIS and GEORGE L. HOXIE. New York, John Wiley & Sons, 1903. Pp. 246.

There are to be two volumes to this work on Electrical Machinery, in which both direct and alternating currents and machines are to be treated. Volume I. covers the laws of the electric, magnetic, and electrostatic circuit, and is intended as an introduction to Volume II., in which the construction and performance of electrical machinery is to be discussed.

The material of Volume I. is stated to be the result of several years of experience in the class room at Cornell University. The plan of the book is to found the treatment of the subject upon the laws of alternating currents and to consider continuous current phenomena as special simplified cases of these. While this is scientifically the most general plan it would seem to make the understanding of continuous current phenomena unnecessarily difficult for the student. The authors state, however, that they have found that this plan maintains the interest of the student and economizes his time, and that it has given very satisfactory results at Cornell.

The first volume is divided into ten chapters with the following headings: "Electricity and Magnetism," "Periodic Curves," "Complex Quantities," "Laws of the Electric Circuit," "Electric Power," "Magneto Motive Force," and the "Laws of the Magnetic Circuit," "Rotating Magnetic Fields," "The Electrostatic Field," "Losses in Electric Circuits." In the first two chapters the elementary principles and units of

electricity and magnetism are briefly given; these are illustrated with a number of problems and with clear diagrams. Periodic curves are taken up at length by graphical and analytical methods. Fourier's theorem and a method for the general analysis of any periodic curve are given in detail, and the application of the method is shown by a number of examples illustrated with exceptionally clear diagrams many of which occupy a full page. In the chapter on complex quantities this analytical method for expressing vectors is explained and the algebraic operations with complex quantities are given. These are made use of in the next chapter for solving series and parallel circuits with resistance, inductance and capacity. Graphical methods are only given for a few simple series circuits, but not for parallel circuits.

Electric power calculations in alternating current circuits are discussed in Chapter VI.; the errors involved when equivalent sine waves are used for irregular waves are carefully pointed out. A power problem in irregular wave forms is given in detail, the correct power being calculated by means of harmonic component E. I. products.

The chapter on electrostatic field is unique and full of valuable material, much of which represents the researches of Prof. Ryan. The existence of an electrostatic flux circuit is shown and an attempt is made to compare it with the magnetic flux circuit. The phenomenon of corona is discussed in detail and a number of experiments are described to illustrate corona effects. The authors point out that insulators for high potentials must be so proportioned that the dielectric flux set up through them will not be sufficient to cause corona, because this would be highly destructive and would also represent a considerable waste of power. The necessity for avoiding corona formation in dielectric strength testing is also explained, and the precautions which must be taken to avoid this are stated. In the appendix a short discussion is given of the limiting voltages for transmission lines. A table giving the minimum diameters of wires to avoid corona for voltages from 50,000 to 250,000 when the distance between the wires is 48 inches is given. In the last chapter on losses in electric circuits mathematical discussions of the various losses are given and a number of formulæ are deduced. Some experiments on a high potential transmission line made by Mershon are described and the results of these tests are compared with those obtained from the mathematical laws.

It may be safely said that this book is unique among electrical books, and that it forms a valuable addition to electrical literature. It is written throughout in exact and concise language and is illustrated with many clear and carefully executed cuts. Over seventy problems are given, many of which are completely solved in the text. This is a valuable feature for the student.

While the book is primarily intended for technical schools, for which purpose it is admirably adapted, it will also prove most valuable to the practicing electrical engineer. It is to be hoped that its companion volume will soon make its appearnce. A. F. GANZ.

Secondary Batteries, their Theory, Construction and Use. By E. J. WADE. The Electrician Printing Co., London; D. Van Nostrand & Co., New York, 1903. Pp. ix + 492.

This volume may be conveniently divided into four portions. The first contains a very complete description of the various forms of storage battery introduced since 1881 and a brief chapter on secondary cells in which other substances than lead are employed. A second part deals with the properties and behavior of lead cells with numerous diagrams giving the characteristic curves for the performance of secondary batteries under varying conditions of charge and discharge, one chapter is devoted to the chemistry of the lead cell. This portion of Mr. Wade's book is followed by a series of chapters dealing with the design, manufacture, treatment, testing, erection and regulation of storage batteries. These chapters containing as they do numerous facts of practical value based upon actual experience are of especial value to those engaged in the installation and management of batteries.

The volume closes with a chapter entitled "Present day cells" in which those forms which have established themselves in England and the United States are considered in greater detail. The prevailing forms in use on the continent of Europe are likewise noticed but more briefly.

E. L. N.